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CERTAIN PHASES OF GLACIAL EROSION

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Oscillation, more or less rhythmic, seems to be a phenomenon of the intellectual, as well as of the physical world. The doctrine of glacial erosion has its ups and downs in quite typical undulatory fashion. It seems that even individuals at times ride on the crest of the wave of advocacy and at other times sink into the hollows of doubt. These moods are apt so to distribute themselves that while some workers are on the crest others are in the trough. The crest-riders have recently been much the most in view, but just now voices from the hollows of doubt are heard. The president of the British Association for the Advancement of Science, speaking from official vantage ground, voices a cautious skepticism as to the glacial parentage of certain kinds of configurations that are held by others to be the erosive offspring of glaciers.[1] Professor Garwood goes beyond the measured skepticism of Dr. Bonney and gives a critical analysis of his grounds of doubt and laudably matches his destructive criticism with constructive interpretations. In these interpretations, he marshals topographic phenomena in support of the view that *protection*[2] is the characteristic effect of glaciers rather than erosion.

[1] T. G. Bonney, Presidential Address before B.A.A.S. (Sheffield, 1910), *Science*, XXXII (1910), 321–36, 353–63.

[2] E. J. Garwood, "Features of Alpine Scenery Due to Glacial Protection," *Geog. Jour.* (September, 1910), pp. 310–39.

So, too, among those who believe in the efficiency of glacial erosion, there has long been some doubt as to the truth, or at least as to the adequacy, of some of the processes to which the erosion has been attributed.

It seems worth while, therefore, to add to the growing mass of matter some notes suggested by phenomena recently seen by us, without presuming that much is new either in the observations or in the suggestions.

I. THE CRITICAL STAGE FROM WHICH CERTAIN EROSION TYPES START

It has seemed to us advantageous to study the initial stages of erosion to see, if possible, precisely what action gives the start to the type of erosion which thereafter controls the configuration, for it is the initial turn that most delicately measures the balance between the opposing tendencies.

The contours that spring from ordinary wear and weathering are well known and may be restored from remnants when the greater part has been lost. Even when there has been no change in the agent and only a slight change in its mode of action, the old configuration can be distinguished from the new; as, for familiar example, the remnants of a peneplain are commonly made out with confidence after most of the plain has been cut away by the rejuvenation of the very drainage system that formed it. Much more clearly can remnants of contours be rebuilt into their originals when some *new* agency intervenes, especially a new agency whose habit of sculpture is distinctively at variance with that of the previous agency.

As surface configurations are traced from regions dominated wholly by ordinary wear and weathering into regions that have been affected by local glaciation, it is usual to find the lower slopes of the unglaciated region and, in the main, the brows and tops of its hills and higher elevations, up to a certain limit, marked by contours of the familiar wear-and-weather type whose interpretation is clear and whose restoration, when mutilated, may be made with great confidence. As such contours are traced into higher latitudes or higher altitudes where local glaciation has entered

sparsely as a modifying factor, it is usual to find the flowing contours of the wear-and-weather type replaced in certain spots by a type that may be said to be unconformable to the prevalent one, a type in which concavity replaces convexity, a type in which the surface has been broadly scooped out locally rather than rounded off generally or narrowly incised. The broad scoop-like mode of excavation, as distinguished from the gully-form mode of narrow incision, is held to be distinctive in that it implies an agency that deployed its effects laterally rather than one which concentrated its action on axial lines. This, it is to be noted by way of precaution, is a distinction that applies chiefly to the initial stage of the two modes of erosion. They remain distinguished throughout but are not so declaredly diverse in later stages.

The lodgment of snow, which is the primary factor in glacial work and determines its initial deployment, is controlled by the wind to an exceptional degree, and wind action is chiefly horizontal in its effects and is thus distinguished from rainfall and run-off, whose dominant actions are vertical. While the very first phases of this difference of action are not very important in themselves, they are believed to be significant as the initial factors in the localization as well as the deployment of the two classes of erosion.

The relative locations of greatest rain-work and greatest snow-work respectively.—Precipitation is intimately dependent on the ascent of air so well laden with moisture that it reaches saturation by reason of the expansion and cooling caused by the ascent. It is for this reason that the ascent of moist air caused by rising over the windward face of any marked relief of the topography determines precipitation on or near that face. As is well known the windward sides of mountain chains thus receive more precipitation than the leeward sides, as a rule. This holds true of snow-precipitation as well as rain, though the snowfall is less prompt and less well localized. Where mountain ranges are broad and complex the snow caught on the windward side is usually greater than that which lodges on the leeward side, and the glaciers on the windward sides of mountain ranges are usually larger than those on the leeward sides. But such *general* community of distribution does not hold in detail, for the wind comes in as a

local differentiating agency. Acting on rain, wind increases the amount per unit area that strikes the surface of an eminence on its windward side; it also somewhat increases the force of the impact on that side. On the other hand, wind tends to drive falling and fallen snow around the wind-swept side of the eminence into its lee and to heap it up in the eddies there, and on the areas protected from the wind. Thus the snowfall that, in the absence

FIG. 1.—Snow lodgment on the side of the summit ridge of Mt. Victoria, Canadian Rockies. This ridge forms the continental divide. The snow has lodged on the Eastern or Albertan side in the lee of the crest. Photo. by R. T. C.

of wind, would come to rest on the windward and lateral slopes of an eminence and later must drain away on these slopes is, under the action of wind, concentrated notably in patches in the lee. Considered therefore in detail, rain action is somewhat intensified on the windward side of prominences, while snow lodgment, leading on toward glacial action, is more markedly concentrated on their leeward slopes.

The field use of this distinctive localization of rain-work and of snow-work respectively is qualified by the fact that, while the

prevalent air movement of a region may be nearly constant in *general*, the cyclonic movements that are the immediate agents that bring on precipitation introduce variation in the *particular* direction from which the wind blows at the critical time when the storm is on and the distinctive work in question is done. In the mid-latitudes of the northern hemispheres, the general air movement is toward the east but at the times of storms the wind not uncommonly comes from the eastward. However, the general law that snow lodgment is most abundant on the prevailingly leeward sides of prominences seems to hold good. This is greatly aided by the shifting that takes place in the intervals between storms.

The fact that the eddies formed in the lee of crests, domes, and knobs are the common spots of lodgment carries as a corollary the observation that the forms of the snowfields are usually broad, or ovoid. The windward edge is usually arched, and is often thickened near its upper border. Not unfrequently the thickened snow mass is wider transversely than in the line of slope. Often, too, it must be noted, the lodgment is concentrated in ravines and valleys that were shaped previously by drainage erosion, and in such cases the localization is less distinctive.

The case best suited to a discriminative study is a broad or transversely elongate lodgment of snow in the lee of a well-rounded eminence from which the normal run-off is divergent. So long as such a snow mass lies passively where it lodged, there can be little doubt that it is protective rather than erosive, when compared with normal surface action. So long, too, as the later action is confined to a slow annual melting of the snow and a quiet run-off of the resulting water, the snow and water combined perhaps do less erosive work, on the whole, than would be done by the more forceful impact and the more prompt run-off of the equivalent rain, though qualifying conditions must be recognized on both sides.

The case of snow vs. rain, under these conditions, is not more than debatable at most and the modes of erosion in the two cases are essentially identical.

But when the snow accumulates perennially so as to move as snow-ice in glacier fashion, the modes of erosion become diverse,

and *the configuration of the eroded surface* is the test of the dominance of the one or the other type. It is obvious that the least eroded part of the eminence must come to stand forth and the

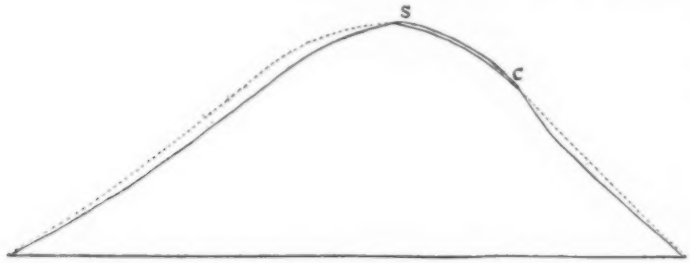

FIG. 2.—Diagram to illustrate the effect of erosion upon a hill, on the assumption that the capping of ice, SC, is protective. The dotted line represents the original outline of the hill; the solid line, the contour resulting from erosion.

most eroded part must retire toward the center. If the snow-covered flank or brow is indeed a protected area, it must gradually come to stand forth from the retiring wear-and-weather contours

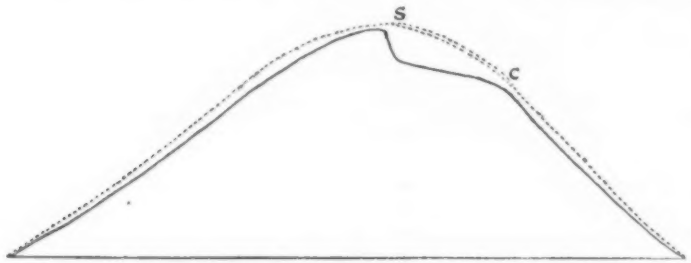

FIG. 3.—The same hill as in Fig. 2, eroded according to the hypothesis that ice is a superior eroding agent. SC represents the original snow bank which comes to occupy a basin as erosion goes on.

adjacent, as a rather definite embossment, as illustrated in Fig. 2. As time goes on, the summit of the hill should migrate toward this protected area and it should tend to become the summit, while the snow-cap in turn migrates into its lee. A marked asymmetry should gradually develop.

On the other hand, if the snow mass, accumulating from year

to year, comes to take on motion as a glacial body, the erosion to which its motion gives rise must take a form coincident with the moving part of the snow-ice mass. The erosion is assumed to be due to the adhesion of the snow-ice mass to the ground on which it rests—to the soil and loose rock at the start, to the progressively loosened and ground rock below later. A broad patch of soil and loose rock coincident in form with the moving part of the snow mass is first dragged away and the configuration of the scar is distinctive of the action. If erosion beneath the moving glacier mass continues the excavation will in time come to have the form shown in Fig. 3. Such excavations are to be looked upon as embryo cirques. They are found on the lee crests, brows, and slopes of round-topped mountains known to have been subjected to local glaciation. Less typical initial cirques are formed in ravines where snow lodgment gives rise to glaciers.

If absolute certainty that there has never been any previous glacial action in a given region is regarded as a prerequisite to an irreproachable illustration of this class of actions, such a case is difficult to demonstrate because the configurations left by the older glaciations have often been so largely lost in the subsequent sculpturing of the common wear-and-weather type that the absence of previous glacial work is hard to prove in regions likely to have been glaciated recently, but this is only a question between the work of different glacial stages, not between glacial and aqueous methods. But though a region has been subjected to previous *general* glaciation, even rather recently, geologically speaking, the typical effects of local glaciation on rounded contours are discernible much as in wholly unglaciated regions, for the contours shaped by the *general* ice movement conform to the dominant horizontality or the low inclination of such general ice movements, while the lines of local ice movement are decisively downward in conformity to the *local* slope.

These considerations are here put in the theoretical form, but they suggested themselves almost as inductions during a summer trip along the coast of Norway in 1909. They arose naturally from the abundant and instructive phenomena of that region, where former glacial action merges into present action. The configurations

wrought by the older general glaciations do not seriously mask the distinctive work of the local glaciation that has followed and is, in some part, in action still. Broad excavations of the initial cirque type are common on the brows and slopes of the rounded mountains and on the islands that fringe this coast and on the mainland itself. They seemed to us clearly to be more common on the eastward sides of the islands than on the westward. The initial types are chiefly the products of modern action; indeed in

FIG. 4.—Basins hollowed in a hillside by tiny glaciers. From the coast of Norway. Photo. by R. T. C.

many cases the basins are still occupied by the snow-ice mass to which their shaping is due. The whole series taken together show various stages of the work of snow accumulation and earth excavation. Small, relatively wide basins, scooped broadly from hillsides, are variously occupied or empty according to altitude, latitude, or other condition favoring snow accretion or snow wastage. Their dimensions range downward to hollows not unlike pits on the brows of drift hills and upward to mountain cirques of typical form and magnitude. They also range from mere cirque heads to cirque heads with short glacial appendages and thence on to longer and longer glacial tails until the peculiarities of the

head-work in the cirques are lost in the more familiar body-work and tail-work of the more accessible parts. Various stages and transitions are shown in the accompanying photographs.

Fig. 4 shows five well-developed basins escalloped in a hillside. The two hollows on the left are round and wide and terminate below in well-defined platforms or steps at nearly the same level.

FIG. 5.—A concave scallop on the brow of a projecting embossment. Apparently this is the work of sapping by the ice at the base of the cliff. Note the rounded convex glacier-polished outlines of the rest of the embossment. In the background is the Lyskamm, central Pennine Alps. Photo. by R. T. C.

They are approximately as wide as they are long, showing that the ice which accumulated there has eaten its way in a distinctly broad fashion into the rock slope on which it lay. The vertical distance which any given part of the ice has moved its rock is small relative to the total amount of transportation accomplished. The work has been done very locally compared with the longitudinal movement of typical water action. The next two basins continue down the slopes to points much nearer to the sea. There has been

more advance movement of the ice here. The basin on the right has become a glacial valley in an embryonic stage and the work of water erosion seems to form a larger factor.

Sculpturing of similar sort is illustrated by Fig. 5, from the Swiss Alps. The brow of a long spur descending from the Zwillinge has been scooped and hollowed in concave fashion by the sapping action of glacier ice. Occurring in the midst of a still

FIG. 6.—The Glacier des Grandes Jorasses on the Italian side of the chain of Mont Blanc. The ice has sunk its bed into the rocky mountain wall and worked backward as implied by the distinct bench upon which it rests. Photo. by R. T. C.

strongly glaciated area, this case is interesting for the reason that such sculpturing has been at work here for a comparatively short time only. The rounded rock contours below and to the right of the hollow excavation have at no distant date been scraped and polished by the larger glaciers descending from the peaks above. The ordinary abrasive action of a moving body of ice is here illustrated. But the much smaller mass of snow and ice at the base of the cliff in the hollow appears to have operated in the very different and more potent manner of basal sapping at the schrund line.

Fig. 6, from the chain of Mont Blanc, represents the Glacier des Grandes Jorasses on the Italian side of the rugged mountain mass of the same name. Other similar glaciers to the left and right have etched their basins into the upper slopes of this great mountain rampart. These glacier-filled basins are deeply sunken and are as broad or broader near the base of their cirque walls than they are farther down toward the ends of the present ice tongues. At their heads they are terminated by precipitous rock walls. Extremely precipitous cliffs come down to the Glacier de Rochfort from the Aiguille du Géant and the col between it and the Aiguilles Marbrées. From these rock walls behind the ice there is a very decided change in slope to the gentle incline of the glacier floor below. In just the same way there is a very abrupt change of slope from the precipitous rocks of the Grandes Jorasses and Mont Mallet to the very moderately inclined surface of the Glacier des Grandes Jorasses at the foot of these steep cliffs. It is at the point where these cliffs join the less inclined basin floor beneath the glacier that the greatest cutting has occurred. Such a profile of cliff and floor coming together at a sharp angle is quite unlike any gully erosion developed by ordinary running water in mountains of massive crystalline rocks. The greatest cutting has been beneath the glacier in the neighborhood of the bergschrund and directed backward into the mountain.

II. CERTAIN SIGNIFICANT POSITIONS OF CIRQUES

In our sketch of the initiation of cirques, we gave preference to cases located on leeward aspects of eminences favorable for snow lodgment but unfavorable for the concentration of running water. We noted that if the lee brow were *protected* by its snow covering, the crest should slowly shift toward the protected spot and the protecting snow-cap should shift in turn to its lee and thus combine to shape forth an asymmetrical mountain horn. On the other hand, if the snow mass becomes a superior *erosive* agent when it begins motion, and digs out a broad basin which in turn adds to the catchment of snow, and if at the same time the embryonic glacier stopes headward, it, in its way, *moves toward a summit position*. It is clear that rainfall does not concentrate toward

the summit of a rounded eminence in this way. Its trenches do advance headward, but they take the form of ravines, gulches, and gullies eating sharply, not broadly, backward. The positions of cirques that are fully developed may be studied for evidence confirmatory of these deductions. In such study perhaps the most striking illustration of summit-ward creep is found in the *crater cirques*, a form that has attracted the attention of observant travelers but has not played as large a part in glacial literature as

FIG. 7.—The Rendalstind on the west side of the Lyngenfjord, Norway. The summit has become crater-shaped by ice sculpturing. Photo. by R. T. C.

perhaps it should. Mountains with crater-like summits are quite common along the Norwegian coast above the Arctic Circle, and they are likewise frequent enough in the Lofoten Islands to give characteristic profiles to the views obtained there from passing steamers.

The Rendalstind, on the west side of the Lyngenfjord (Fig. 7), is an illustration of the type in a not very advanced stage of development. Glacier action in the summit basin is today actively in progress. Other mountains of the region reveal much more pronounced sculpturing of this sort where the action has either been more prolonged or more intense. Such a case is illustrated by

Fig. 8. This crater mountain, which happens to be crossed by the 70th parallel, comprises the north end of Kaagö Island. Originally it appears clearly to have been a more or less rounded dome or knob. A cirque starting with snow lodgment high up on the northeast slope of this eminence appears to have worked back

FIG. 8.—A crater-like mountain top in a more advanced stage of erosion. The outer slopes of the conical mass show the familiar abrasive action of past general glaciation together with the lines of ordinary meteoric erosion. The steep walls of crater-like cirque are due to sapping by localized glaciers of late date. Kaagö Island, coast of Norway. Photo. by R. T. C.

toward the summit by a stoping process until the cirque pit has come to occupy a sub-summit position. The mountain top has been hollowed out and now only a shell remains in place of the former flat-topped mass. It is like a volcanic crater broken down on one side. The inner walls are steep and cirque-like and the crater portion is filled with deep snow. Water erosion is not adapted to this sort of sculpturing. The central basin with circular cirque cliffs gives every appearance of having resulted from

FIG. 9.—A very capacious summit cirque in the San Juan Mountains of Colorado. Seen looking southeast from the culminating point of St. Sophia Ridge, Telluride quadrangle. The points of note are the breadth of the cirque basin and the narrowness of the serrate rim. The abrupt step in the middle of the basin while partly the result of stoping beneath the body of the glacier was also probably in part determined by differences in the resistance of the rock formation. Photo. by R. T. C.

continued sapping and quarrying by glaciers eating their way backward much as they have in the Alpine cases cited.

Fig. 9, from the San Juan Mountains of southwestern Colorado, is a striking example of a much more capacious summit cirque. The basin here is very broad, with a nearly level floor, while the cirque rim has been undercut till only a narrow horseshoe-shaped serrate ridge remains. Its jagged crest varies in altitude from 13,000 to 13,200 feet, while the mean elevation of the broad floor is about 12,800 feet. The breadth of the basin and the steepness and thinness of the amphitheater walls that skirt it show that this type of action has here gone about as far as it well could as a single stoping operation. The whole constitutes a signal case at its very climax.

In the light of these illustrations, particularly Figs. 8 and 9, there seems no ground to doubt that the erosion suffered by the non-glaciated parts in such situations at least falls greatly behind that suffered by the parts covered by ice.

III. THE DISTINCTIVE WORKING FACTOR

The decided superiority of moving ice over moving water as an erosive agent lies chiefly, we think, in the rigid hold of the ice on matter set in its base or sides. This is sharply contrasted with the adhesion of water which is so feeble as to scarcely warrant the term "hold" at all. Water action finds some compensation, indeed, in the higher velocity it usually gives to the matter it carries, but near the point of origin of action—and this is the location chiefly under discussion here—the water is so distributed as not to be able to acquire much efficiency from concentration. The ice mass, on the contrary, is rigidly unified; its velocity is indeed low, but its mass and fixed coherence are high. It is in respect to this coherence that exaggerated views of the viscousness of ice are perhaps most misleading. Rigidity of grasp and mechanical firmness of action are specifically implied in the groovings, gougings, and crushings that distinguish the action of glaciers. Effectiveness of corrasive action is further implied in the chemical and physical nature of the rock-flour and fragments which these groovings, grindings, and crushings contribute to the glacial till

and to the wash-products immediately derived from it through glacio-fluvial assortment.[1] The graving of a glacier's bed by rock fragments set in its base or sides may be cited as specific evidence of an essentially rigid hold on the graving tools, and of an internally rigid, rather than fluent, motion of the mass holding the tools. The glacial grindings that are borne out with the subglacial waters and give milkiness to glacial streams seem to us irrefutable evidence of effective rasping and grooving of the rigid type, not of simple viscous overcreep. The very marked contrast between the turbid waters that flow from beneath glaciers and the relatively clear waters that flow down adjacent unglaciated valleys is very impressive and spectacular evidence of the superior erosive powers of glaciers.

Closely allied to this lesson from grindings in transit is a less obtrusive one drawn from the contrast in the points where coarser matter which only strong transporting agents can handle is concentrated respectively in glaciated and in non-glaciated valleys in regions of the same general type. The upper parts of non-glaciated mountain valleys in cold regions are usually burdened with heavy talus and large loose masses which the drainage is unable to carry away, while the glaciated parts of similar valleys are usually well scoured out and the moutonnéed sides and bottoms of U-shaped troughs take the place of the craggy outliers of V-shaped trenches in unglaciated valleys. But in the lower portions of the glaciated valleys below the reach of recent glacial action, *aggradation* very generally prevails, while in similar non-glaciated valleys *degradation* generally prevails, if not absolutely, at least relatively. Students of Alpine regions will recall multitudes of illustrations. A similar lesson is even more impressively enforced on the borders of the late Pleistocene glacial areas. In strong contrast to the state of the valleys of the adjacent driftless regions, the great glacio-fluvial valley trains with their thick heads next to the ice border, as well as the frontal aprons, show very conclusively the overladen condition of the glacial waters and their marked incompetency to fully carry away their burdens.

[1] "Hillocks of Angular Gravel and Disturbed Stratification," *Am. Jour. Sci.*, XXVII (May, 1884), 378–90.

Now the regional precipitation is much the same for like areas and like situations in the glaciated and in the non-glaciated valleys. Such differences as there may be appear to favor a greater run-off in the glaciated than in the non-glaciated basins, for the former are likely to be cooler and hence better condensers and the concentration of snow by wind action is there more effective. If so, the advantage in absolute carrying power lies with the waters of the glaciated valleys. If therefore the passing of a part of the precipitation through the glacial form and the moving of this part, so far as it moves as ice, is *protective*, the débris should tend to remain in the upper glaciated sections thus protected; while the waters of the valley below the glacier having some excess in volume and having less burden to carry should tend to degrade the lower reaches of the valley more effectively than if the glacier were absent. That the facts are precisely the opposite seems good additional evidence that the glacial form of water compared with the aqueous form increases notably the corrasion and the transporting power. And so it seems to us that the fringing outwash aprons and the thick-headed valley trains of the Pleistocene join with the aggraded states of the lower stretches of present glacial valleys and with their turbid glacial streams, their moutonnéed walls, and their glacial scorings to testify to the superior erosive efficiency of glaciers.

Traced back analytically to the properties that gave rise to them, these corrasive products point to a glacier's power to take firm hold on rock fragments imbedded in its base and sides and move them on while it uses them as graving tools. A special feature that is of interest here is the ice's habit of freezing to fragments in contact with it, especially when moisture is present. Ice also strengthens its adhesions by a tendency to freeze and thus to attach additional ice at points where tension is developed. This amounts to an inherent tendency to strengthen its hold when threatened with severance.

IV. THE EVOLUTION OF THE CIRQUE

In a young glacier-head just coming into action as the result of the growth of its stresses as a snow mass, it is inevitable that

at some point near the upper edge of the snow mass there should come to be a line of strain between the thicker part below that is forced to move and the thinner part above that lacks sufficient stress to take on motion. A low temperature is essential to the preservation of the elements that enter into the process. Through this low temperature the snow-ice mass has become adherent to the soil beneath it and more or less interlocked with the loose rock that may be at or near the surface. The motion of the snow-ice mass involves the motion of some part of this underlying material. Under the snow-protected stationary part the loose earth-surface remains behind. The line of division between the stationary protective snow and the moving abrasive snow-ice mass thus demarks a scar and this scar, if we interpret aright, is the embryo of the future cirque. As the process goes on and the excavation becomes deeper and by this deepening comes itself to aid in the catchment process, the line of transition from the ineffectively thin snow above to the effective deep snow below becomes more sharply defined. Thus the delimitation of the growing glacier-head and its product, the growing cirque, not only becomes more pronounced but the line of parting between the active and the inert becomes fixed by the process itself; and so the declared cirque becomes established and its bergschrund localized. With further progress the action graduates into the still more declared forms of the cirque-generating process.

In the exposition of Willard D. Johnson[1] as also in that of G. K. Gilbert,[2] both of which we accept in the main, the bergschrund is made the dominant agency in the cirque formation. The view just outlined carries the cirque-forming action back of even the cirque itself and, potentially at least, back of any bergschrund or any possible influence arising from the bergschrund. It makes the bergschrund and the cirque-development sequent on conditions and agencies that at an earlier stage controlled the snow-ice accumu-

[1] Willard D. Johnson, "The Profile of Maturity in Alpine Glacial Erosion," *Jour. of Geol.*, XII (1904), 569–78. Earlier papers are "An Unrecognized Process in Glacial Erosion," *Science* (1899), p. 106; "The Work of Glaciers in High Mountains," *ibid.*, 112–13.

[2] G. K. Gilbert, "Systematic Asymmetry of Crest Lines in the High Sierra of California," *Jour. of Geol.*, XII, 579–88.

lation and brought on motion in the thicker part of the mass while it left the thinner part stationary and protective. The bergschrund and the cirque cliff are themselves made sequences of a mobility and erosive competency more primitive than themselves. This in turn is contrasted with adjacent inertness and erosive inefficiency.

All this, however, seems to us wholly compatible with a cordial acceptance of the bergschrund and the cirque wall as auxiliary sequential agencies which strikingly abet the more primitive actions that brought them into being. Much as the bergschrund may aid the backward sapping of the cirque wall, we think that the more fundamental agencies are to be regarded as controlling the process throughout its history.

As already implied, a marked peculiarity of ice, shared in equal degree by no other familiar body, is its tendency to grow under tension and to form adhesions by such growth at the points where tension has been developed. When forced to part, ice parts suddenly by abrupt fracture attended by the elastic recoil of the separated faces. In this its action is in marked contrast to the separation of viscid bodies, which part by a gradual weakening and stretching under continued strain. Within the bergschrund, as also elsewhere and in general, the predisposition of the ice, when at the critical temperature of congelation and below, is to freeze to whatever falls in from the surface or is loosened from the walls. This tendency to form adhesions is no doubt especially active at the base of the schrund and at the foot of the cirque wall, where the convergence of the walls wedges all such matter together and where the conditions of temperature and moisture are likely to be favorable to glacial attachments in the active season. Whatever snow falls in, slides in, or is blown into the gaping mouth of the schrund, and whatever rock is detached from the cirque wall by the freezing of such waters as may come down the bergschrund are subject to such attachment to the head of the glacier and to removal by it as it moves, as Johnson has indicated. In addition to this, such waters as enter the mountain at any point above the cirque and traverse internal joints and later come out to the face of the cirque wall lower down are subject to freezing as they come near the

exposed portions of the face, and by expansion in the joints are likely to rive the wall rock and to detach fragments from it. It seems probable from the nature of the case that the exit of such internal drainage takes place more largely at or near the foot of the cirque wall than at higher levels. Such a localization of the action is specially fitted to promote basal sapping. If the sapping at the base of the cirque wall be thus made in some notable part dependent on the seepage of water from the mountain mass at or near the base of the wall, it will not perhaps seem strange that the sapping should proceed somewhat downward as well as backward, following in reverse the direction that the waters of seeps and springs usually take in issuing, and thus give rise to the important fact observed by Johnson that the floor of the cirque frequently inclines somewhat toward the cirque wall.[1]

In this view, the sapping is not made in any radical way dependent on diurnal changes of temperature due to the openness of the schrund above; rather it presumes that the base of the schrund will often be filled with snow, ice, or rock fragments fallen from above and that it will not be freely exposed to the briefer class of changes of temperature that affect the outer air. It does presume, however, that the mean temperature at the base of the schrund, and at the base of this part of the glacier generally, favors freezing whenever tension aids, and that it is favorable to glacial growth rather than glacial wastage, as this is the general fact in this part of a glacier. The periodicities of seasonal temperature and the variations attending the cyclonic movements of the atmosphere extending over some days seem to us more probably effective in the sapping at the base of the cirque wall than daily changes.

V. GLACIAL STEPS

Conditions somewhat similar to those of the cirque, save in the matter of the beginnings of motion, are often found at other points along the length of the glacier below the cirque. They do not seem to be in any way dependent on the existence or the absence of a declared cirque at the head of the glacier. If a glacier takes origin in a sharp gulch or in a pointed valley, a typical cirque

[1] Willard D. Johnson, *Jour. of Geol.*, XII, 576.

may not develop, but this does not affect the behavior of the glacier below. If a pre-existent step or down-set crosses the bottom of the valley at any point beneath a glacier, or if a step is developed by structural inequalities, and if the down-set is sufficiently great in proportion to the thickness of the ice to cause effective crevassing

FIG. 10.—View from the Bäregg in the Bernese Oberland, Switzerland. At the bottom of the picture below the ice fall is the comparatively level Lower Eismeer of the Unter Grindelwald Glacier. Above the ice cascade is another higher ice plateau known as the Fiescherfirn, limited by the slope seen in the perspective. Peeping through the mists high above is the point of the Grosse Fiescherhorn. Photo. by R. T. C.

through the whole depth of the glacier, the conditions at the base of the step are not radically different from those at the base of the cirque wall, for there is in effect a break in the continuity of the motion of the glacier and the beginning of a new motion in the ice mass below. The rock face of the step may be regarded as a cirque wall in a modified sense. From it masses may be detached and, falling against the ice wall, become attached and dragged

forward. At the brink of the step-wall special weighting is likely to be brought to bear by the pushing of the ice forward over the brink before it breaks and drops down, and this probably leads to some splitting off of the edge of the wall. This action naturally tends to give slope to the step and to modify it in the direction of a cataract as distinguished from a cirque, but the essence of the phenomenon is probably much the same in either case. Sapping and stoping seem to be rather general phenomena of the basal action of glaciers.

FIG. 11.—The Furgg Glacier, a broad, flat, ice sheet at the east base of the Matterhorn. Both above and below this nearly level glacier-made shelf are steep cliffs. Photo. by R. T. C.

The operation of the stoping process at several points in a long glacier tongue, by developing successive ice falls between more or less level stretches, results in a rude stairway of giant tread. A portion of such a glacial stairway is shown in Fig. 10. This is the Unter Grindelwald Glacier viewed from the Bäregg. Two comparatively level stretches of glacier are visible—one above the prominent ice cascade, the other below it. They are known respectively as the Fiescherfirn and the Lower Eismeer. Dropping from the Grosse Fiescherhorn and lofty Fieschergrat to the gently

sloping Fiescherfirn are steep ice-clad slopes—the upper cirque walls. Dropping in turn from the Fiescherfirn to the Lower Eismeer is the ice cascade in the center of the picture. To the right beyond the range of this picture the level Eismeer plunges over another ice fall toward the Lütchine valley below. The last plunge, however, is perhaps more in the nature of a hanging valley at the approach to the main valley. Cataracts due to the fall of

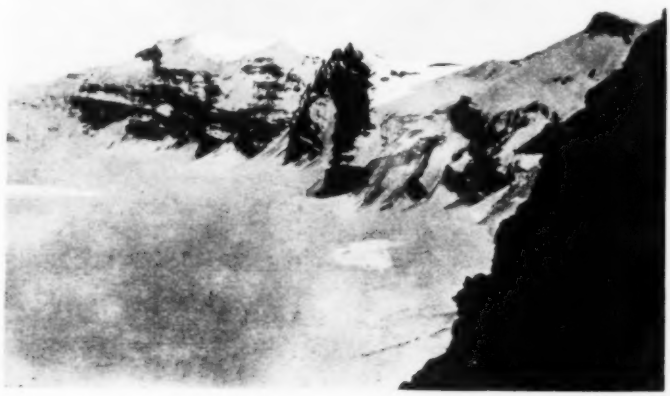

FIG. 12.—Nearer view of the head of the level Furgg ice sheet and the Furggen Grat, whose precipitous walls are being undermined. View from the Matterhorn hut. Photo. by R. T. C.

glaciers from hanging valleys into main valleys are frequent but necessarily occur at or near the junction of the valleys. Cataracts occurring at intervals along the course of a single ice stream are presumed to be correlated with stoping action.

Fig. 11 is introduced as an example of a flat plateau-like glacier-covered tract intermediate between the mountain heights behind it and the lower valley in front. This flat plateau covers an area of approximately four square miles at a mean altitude of about 10,000 feet above the sea. Ice cascades descend toward the

lower valley from either end of it. Behind are the abrupt cliffs of the Matterhorn and the Furggen Grat (Fig. 12). The very sharp angle between the steep wall of the Furggen Grat and the Furgg Glacier which is pulling away from it affords strong evidence of the effectiveness of sapping at this critical location.

VI. BASAL SIDE EROSION

The sapping and corrasion along the side-base of a glacial valley, by which the normal V-shape is converted into the glacial U-shape, is perhaps due mainly to the better supply of carving tools furnished the sides of the glacier by infall and inwash from the slopes and cliffs on the valley sides, and by seepage from the side walls. This supposes a general similarity between the conditions at the side of the valley and those at the cirque base, except that the direction of glacial motion is different.

All these distinctive phenomena of glaciers seem to us to be expressions at once of the peculiarities of glacial erosion and of its superiority where conditions favor glacial erosion.

This view does not, however, make the superiority universal and unqualified. Obviously it does not exclude the view that snow fields while they remain in the passive state serve as protective agencies. Nor does it exclude the view that the center of a continental ice field, from which the motion is mainly radiant and limited in amount, may be protective rather than erosive when compared with normal weathering. Nor does it exclude the view that valley glaciers in some of their parts may be less erosive than normal wear and weathering would be. But these seem to us rather qualifications of the general proposition that glaciers are effective agents of erosion than contraventions of it.

VALLEY FILLING BY INTERMITTENT STREAMS

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Streams having steep grades are usually thought to be in active vertical erosion. The writer finds, however, that many intermittent streams are not degrading but are actively aggrading parts or all of their valleys. One of the best examples of such valley filling is that of Jewell's Creek, described in this article.

This little valley is found on the right bank of the Huron River about two miles above the city of Ypsilanti. The Ann Arbor sheet (U.S.G.S.) shows it as a mere ravine to the west of the little settlement of Superior. The accompanying map shows that the valley is about eight hundred and fifty feet long and that the headwaters are eighty-five feet above the Huron River. The line marking the west boundary of the map is on the line of a fence. The land to the west is under cultivation. The main stream has two tributaries, one from the southwest which enters near the mouth, and another from the northwest, joining the main stream near the head waters. Both of these branches head into cultivated fields.

The main valley is divided into two distinct parts. Above where the forty-five-foot contour line crosses the valley, the flow of the water is intermittent. The floor is thereby mostly dry and covered with a species of grass that can live under dry conditions for part of the year. Below the forty-five-foot contour line the flow of water is constant throughout the year. Here the bottom is mostly wet and covered with swamp grass, which greatly retards the flow of water. Fig. 2, taken from a point near the mouth, gives a good idea of the lower part of the valley; while Fig. 3 gives a view of the middle portion just above the crossing of the forty-five-foot contour. The stump shown in the face of the small cliff in the foreground is indicated on the map by the letter *S*, the trees are indicated by circles, and the cattle are standing just about where the fifty-foot contour line crosses the flat bottom of the

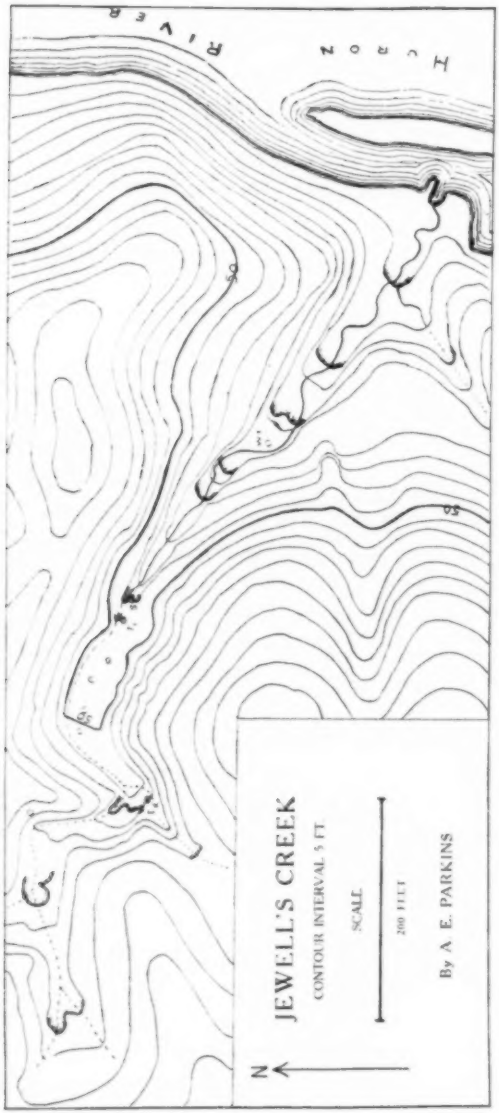

HERON RIVER
JEWELL'S CREEK
CONTOUR INTERVAL 5 FT
SCALE
200 FEET
By A. E. PARKINS
N

FIG. 1

valley. From both the pictures and the map we see that throughout the whole valley we have steps and above each step the valley bottom is flat floored. Only at one point in the valley, just below the forty-five-foot point, is it V-shaped.

The flat floor indicates filling. This is best seen perhaps in Fig. 3. This view also gives other convincing evidences. The sharp angle between the valley sides and bottom is a good evi-

FIG. 2.—The lower part of the valley. In this part there is a continuous flow of water throughout the year, it being below the water table. The water course is much choked with grass. One step may be seen just this side of the tree, a walnut, in the valley bottom near the middle of the picture. On the map the location of the tree is designated by *W. T.*

dence, the buried "feet" of the trees is another, and the most convincing of all is the position of the stump in the face of the bank or cliff. Just above the roots, where the surface of the ground is found with most trees, is a dark layer of soil about three inches thick. This marks the level of the valley bottom before filling. The view also shows that active erosion is going on at this point causing the step to recede up stream. This recession takes place only during and after rain storms and wet weather in the spring. The material taken from here goes to build up the steps in the lower part of the valley.

But where does the material come from that is filling the valley above this step and all the way to the headwaters? All over the valley floor above this point we find fresh sand and gravel. Since there is no evidence that it comes from the sides, it must come from the collecting basins drained by the headwaters of this stream.

FIG. 3.—A view of the middle part of the valley. The forty-five-foot contour crosses on the edge of the tiny cliff. This view shows the flatness of the floor, the sharp angle between the valley sides and bottom, the buried "feet" of the tree and the stump.

The fact that the headwaters lead from cultivated lands leads one to suspect that here is the source of the material, and that the valley began to be aggraded when the forests were cut off and the soil loosened by the plow. This being so, filling must have taken place since the arrival of man in this section. Just how long ago that was, is not easy to determine from anything in the valley, except what evidence may be presented by the stump.

Evidently that seventy-five- or eighty-year-old tree started as a sapling in the valley bottom when the surface was two and one-half feet below the present surface and on a level with the upper portion of dark soil. Filling must have taken place some time within the seventy-five or eighty years. It is probable that filling has extended over many years and was and is necessarily intermittent during the year and intermittent during periods of years, less waste being furnished when the field to the west is in sod and during the dry periods of the year.

If all these suppositions be true, one would be led to make the statement that *all valleys of intermittent streams that head in cultivated fields are waste filled*. To test this generalization search was accordingly made and within a quarter of a mile from Jewell's Creek three others were found that showed essentially the same features as here described. Later, other valleys were examined, in all about a dozen, and invariably it was found that where these streams headed in cultivated fields filling was going on in the valley, the amount of filling depending upon the size of the collecting area and upon the kind of material. Not all showed steps as we have in Jewell's valley, but in most of the valleys this feature was duplicated. It was found that the steps were probably produced by bowlders or brush accumulating in the valley, causing a deposit of leaves and waste on the up-side.

The steps in Jewell's Creek as a rule are higher than any in the other valleys yet examined. The ones that are higher show evidences of their being in rapid though intermittent recession, and from indications on the sides of the valley it is believed that they started farther down the valley where stones and twigs blocked the course of the stream. How could the higher steps be produced then? Let us imagine that we have a gradual slope to the valley floor above this point of blocking, and that at some points the water in times of flood had broken through the grassy cover of the slope and had gouged out a trough with a tiny cliff at the upper portion, as we see just to the north of the walnut tree in both picture and map. Now by recession of this tiny step the cliff at the edge would become higher and higher because the new valley bottom produced by erosion would have less grade than the pre-

vious one. This seems to be the way in which the cliff in Fig. 3 was produced.

From a study of the ten or twelve valleys examined I think it is possible to make the general statements: that valleys of intermittent streams which head in cultivated fields are generally flat floored due to filling; that the filling is intermittent, being affected by kinds of crops, and wet and dry periods; that such valleys are usually characterized by steps; and that these steps are first caused by dams of stones and brush, and may become higher by recession. In all such valleys we have an interruption in the normal cycle of erosion, caused by an increase in the supply of waste brought to the headwaters; and when this supply is decreased the stream will clear away the waste and erosion will go on agreeable to the normal order.

ORIGINAL ICE STRUCTURES PRESERVED IN UNCONSOLIDATED SANDS

CHARLES P. BERKEY AND JESSE E. HYDE

The purpose of this paper is to describe and illustrate certain structures occurring in unconsolidated sands of glacial origin. These structures are so inconsistent with the usual behavior of sands during accumulation that it is believed they point to special conditions that could have prevailed only during the glacial epoch. It may be that they give a clue to marginal structures within the moving ice sheet itself.

The deposit is located in New York City between 134th and 135th streets, west of Broadway. It may be seen from the Riverside viaduct which crosses the Manhattanville depression. It appears as an irregular sand and gravel hill, probably only the remnant of a once much more extensive deposit. While it has been opened at several points to obtain building sand and abnormal features are to be seen in several of them, recent excavation for a building at the corner of 135th Street and Broadway has revealed the most interesting exposures.

With the exception to be noted, assortment of material is excellent. Sands of a wide range in size are extensively represented, usually well assorted and plainly stratified. Rarely the finer silts and clays occur in interstratified streaks. On the other hand, some of the beds are made up of pebbles whose diameters are measured in inches. On the whole the materials are coarse, i.e., sands and gravels rather than silts and clays. The individual layers are usually thin, a few inches only, but some of the finer-grained beds may reach a foot or two in thickness.

The exception to this rather thorough assortment of materials is found in masses of bowlder clay which are intimately associated with the other types. The bowlder-clay structure is very coarse. Bowlders two or three feet through are not unusual and one over six feet in diameter is closely associated with sand and gravel.

FIG. 1.—Assorted sands and gravels standing as steep as 68 degrees at some points. Left is northerly.

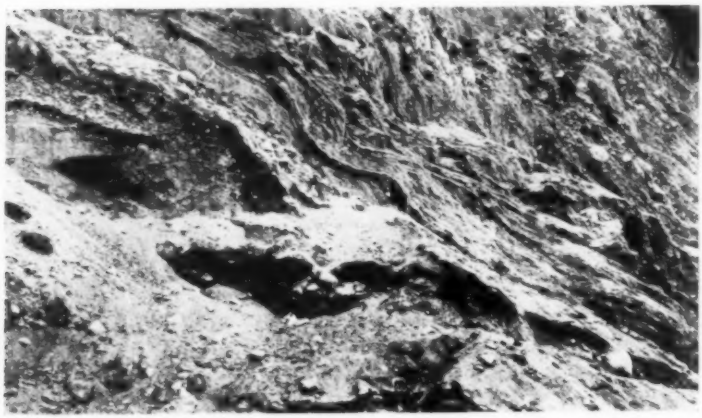


FIG. 2.—Contorted sands associated closely with coarse and unassorted gravels. Right is northerly.

The occurrence of these strikingly unlike deposits so closely interrelated is a prominent feature. Conditions suitable for the handling of large bowlders and the accumulation of till cannot well be regarded as consistent with thorough assorting and deposition of finely stratified sands at the same time and place.

The beds almost never lie flat; when they do it is only for a few inches. They are almost invariably inclined toward the north, northwest, or northeast; that is, against the general ice movement as indicated by striae of the vicinity. Although the maximum angle of repose for unconsolidated sands under subaerial conditions is about 34°, the dips here commonly range from 10° through 20°, 30°, 40°, to 60°. Inclinations of 68° and 71° have been observed and at one point, for a vertical height of four or five feet, the beds are perpendicular or even slightly overturned.[1]

Occasionally contortion is observed but only to a very limited extent. Faulting of several inches displacement has been seen in such form that it could not possibly have happened by slipping on the growing margin of a delta deposit. In one instance the beds on either side of the fault dip away from the fault plane, on the one side at an angle of 67°, on the other side at an angle of 40°. In another instance a small thrust fault of an inch displacement was observed. It is of significance that the thrust was from the north (Fig. 3).

FIG. 3.—Small overthrust in unconsolidated sands, thrust from a general northerly or northwesterly direction.

In order to explain these occurrences and the ones to follow, it may be assumed that the deposit was laid down near the margin of the ice sheet. The material is so well assorted and the bedding is so sharp that it is necessary also to conclude that the deposit was originally water laid. Possibly the dips were originally toward the ice sheet as they are now found, but the angles of inclination could not have been as great as they are now.

[1] Similar structural features are noted by Professor T. C. Chamberlin in gravel hills in Tippecanoe Co., Indiana. ("Hillocks of Angular Gravel and Disturbed Stratification," *A.J.S.*, XXVII [1884], 378–90.)

It seems necessary to assume that, following the deposition, and while the whole mass was thoroughly saturated with water, it was frozen and incorporated in the ice and that there was then

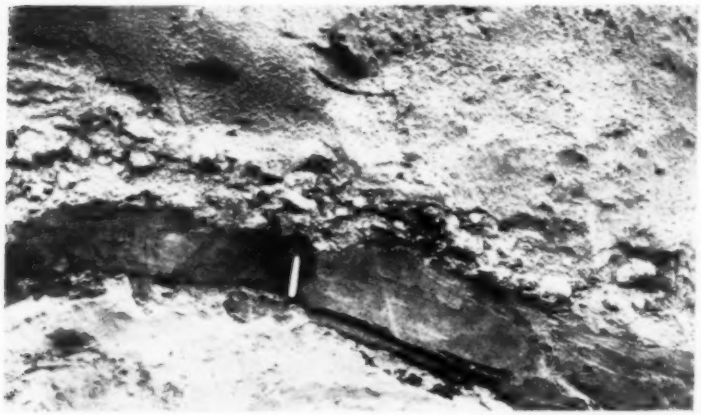


FIG. 4.—A fine sand layer which seems to have been arched since deposition and in the process developed V-shaped notches along the stretched upper margin which are now filled with coarser sand. See explanatory sketch, Fig. 5.

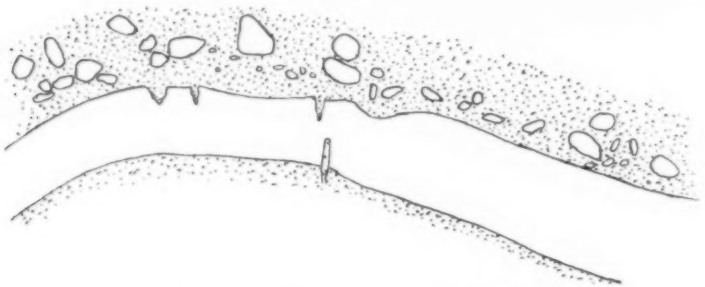


FIG. 5.—Explanatory drawing to accompany the photograph, Fig. 4

movement of the ice sheet with its included material. The movement in the latter, while probably not great, was sufficient to cause the oversteepening of the sands as they are now found, and the slight amount of contortion and faulting which occurs. Under

these conditions probably the interstitial ice became an efficient binder between the individual sand grains and caused the whole to behave as a rock mass, yielding slowly to gradual stresses and breaking or shattering or faulting like a true rock when subjected to sudden changes.

Subsequent melting of the ice left everything in place, and the whole complex mass suffered so little distortion from shrinkage with the loss of its ice matrix that these secondary structural features are still preserved.

With this statement of the thesis some of the minor structures may be described. All of them occur in the finer sand deposits exposed in the excavation at 135th Street and Broadway.

On the south wall there is a low regular arch several feet across in a bed of soft fine clayey sand, perhaps eight inches thick. It is overlain and underlain by much coarser sands. In the upper part there are three narrow vertical cracks some three or four inches deep where the fine sand has been pulled apart, as if by stretching, and the coarse material from above has filled the openings. In this case, the difference in the constitution of the two beds seems to have been a controlling factor and the two types of material behaved somewhat differently, the fine-grained sand layers moving as a unit, and cracking on the upper stretched surface of the arch. The fine sand is now so soft as to be easily pared with a knife and the coarse material runs out from above and below it by its own weight.

At one point on the north wall of the excavation, and less perfectly at several other places, the sand preserves what seems to be the original shattering and cracking of the frozen mass. It is in very fine-grained sand, easily trimmed down without dulling a knife blade. The fracture lines are decidedly darker than the mass of the sand, sufficiently so to bring out the structures in the accompanying photograph. The original sedimentary structure of the sand is preserved and shows distinctly to what extent the whole was crushed and faulted. It is in fact a sand deposit breccia of extremely complicated structure.

A few feet distant from the last, a wholly different structure is preserved. This is in quite fine-grained, clayey sands which

FIG. 6.—Brecciation and minor faulting in unconsolidated stratified sands. For explanatory sketch of the detail see the accompanying drawing, Fig. 7. Left is northwesterly.

FIG. 7.—Explanatory drawing illustrating the most prominent detail of the photograph, Fig. 6, and compiled in part from other photographs of the same occurrence. Only a few of the angular "fragments" of sand are indicated to show the brecciation.

alternate with several thin streaks of coarse sand, the latter seldom exceeding an inch or two in thickness. These beds are inclined at considerably more than the angle of repose under water, reaching about 40°, and have undoubtedly been oversteepened, although scarcely distorted. Traversing this series is a thin, nearly horizontal bed of rather coarse sand, six feet long and one to three inches thick. This sand is for the most part horizontally bedded, but cross-bedding also occurs, showing that it is undoubtedly water laid in its present position. The remarkable thing is that the cross-streaks of the inclined series are continuous above and below this horizontal streak or layer and are interrupted by it, showing that the horizontal bed came in subsequent to deposition and oversteepening.

It is unquestionable that the beds above and below the horizontal one were once continuous. Assuming them laid down, frozen, and over-steepened as described above, it is postulated that a horizontal crevice was formed in the frozen mass and melting took place along it in the ice and that water currents of sufficient force to carry and rearrange the sands were allowed to enter. With the final thawing of the mass these delicate structures were not destroyed and are still preserved in the unconsolidated sands.

Other occurrences in the same deposit exhibit irregular mixtures of fine and coarse sands in which the finer-grained areas seem to represent a bed that has been broken into distinct blocks or has been drawn out into odd irregular stringers. This gives certain areas, several feet across, the appearance of a coarse breccia in which the finer sand areas constitute the angular masses, while the coarser sands fill up the interstitial spaces like a matrix. Again there are places where the oversteepened layers are so closely associated with others whose attitude is consistent with present conditions that the whole group almost baffles explanation in detail.

In conclusion it may be worth noting that most of the structures described and illustrated could not have been produced in these sands in their present unconsolidated condition. The steeper layers on the other hand could not have been originally deposited in their present attitude. It is necessary to introduce some inter-

mediate history. There is little doubt but that the oversteepening, the brecciation, faulting, and some of the mixing of materials of different types were caused by glacial advance involving the

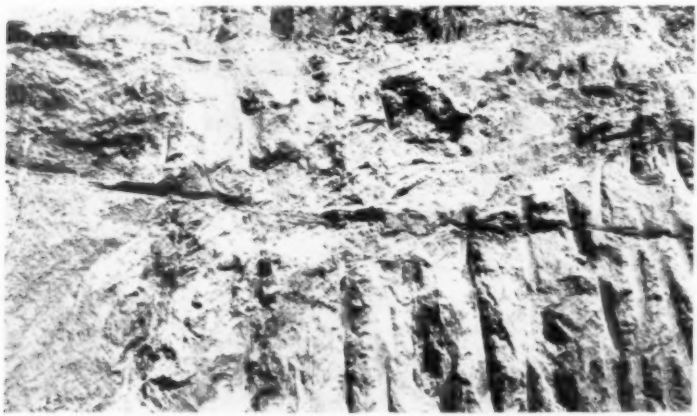


FIG. 8.—Photograph of the thin horizontal sand layer cutting inclined assorted sands. Note the cross-bedding in the horizontal layer at the right. See explanatory drawing, Fig. 9 below. Left is northwesterly.

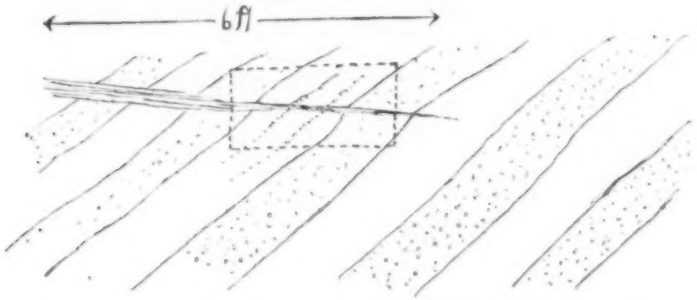


FIG. 9.—Diagrammatic drawing to accompany photograph of inserted sand layer, Fig. 8. The dotted area indicates the portion shown in Fig. 8.

whole mass in some way in differential movements. But before that could be accomplished much of the material had to be assorted, and this had been done, as the great variety and excellent sizing

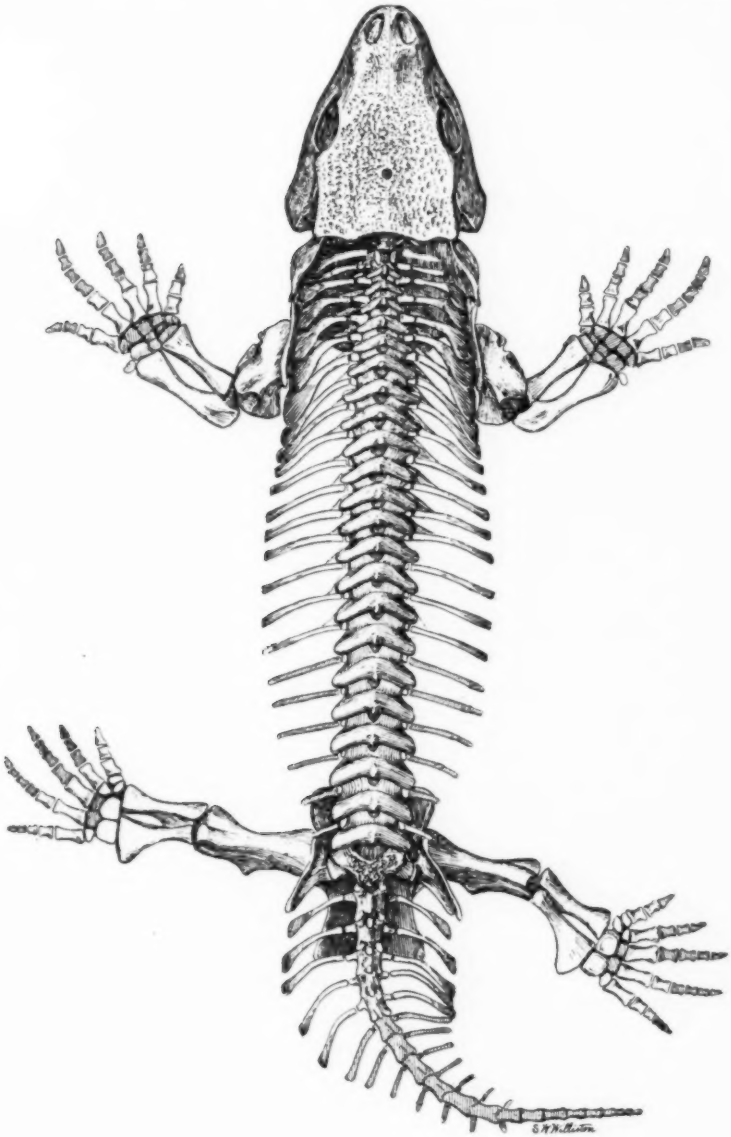
of grains indicate, under extremely variable conditions and in complex relations to unassorted masses. This seems to point to marginal and superglacial accumulation in such relation to the general ice mass that the particles subsequently became incorporated with it and partook of its later movements. These later movements developed the structures just described which may not have been uncommon in other drift deposits but which are probably seldom so well preserved.

Although the original ice behavior is indicated by these structures it is doubtful whether the observations are of much value toward a better understanding of ice flowage. The ice must have been unusually heavily saturated with these earthy matters, the sands and gravels, and it is probable that differential movements were largely encouraged by their differences of texture.

RESTORATION OF SEYMOURIA BAYLORENSIS BROILI, AN AMERICAN COTYLOSAUR

S. W. WILLISTON
The University of Chicago

Few Permian vertebrates are of greater interest than the one herewith figured, as restored from a remarkably complete specimen discovered the past year by Mr. Paul C. Miller in the vicinity of Seymour, Baylor County, Texas. The genus and species were originally described by Dr. Broili in 1904 from two imperfect skulls, the clavicular girdle, and a few of the anterior vertebrae and ribs, found on West Coffee Creek, Texas, and preserved in the museum at Munich. Nothing whatever has since been added to our knowledge of the genus, and the appendicular skeleton has remained quite unknown. Of the numerous genera of amphibia and reptilia from the Texas beds not a few are yet but imperfectly known, making it almost impossible to determine many of the isolated limb bones and girdle bones so often found in those regions. The past year I described various limb bones and vertebrae of a small reptile discovered on West Coffee Creek under the name *Desmospondylus anomalus*, suggesting its possible identity with either *Seymouria* or *Pantylus*, especially *Pantylus*, which also is known only from skulls, one of which is in the University of Chicago collections. The two specimens upon which this genus was based are of almost identical size, indicating that the specimens were of adult animals. They prove, however, by comparison with the later acquired specimen, to be congeneric, and of very immature individuals, so immature that they present a number of embryonic characters not seen in the adult specimens, for by the aid of the articulated specimen others of *Seymouria* previously indeterminable have been recognized among the material of the University collections, all from the same region and horizon, the upper or Clear Fork division. And these additional specimens have aided materially in the production of the restoration because of their



free condition. The specimen found by Mr. Miller was almost completely inclosed in four pieces of a large clay nodule. All that was visible in the specimen as it lay upon the hillside was a small surface of the cranial table, where a chip had been broken off.

The skeleton, as preserved in the nodule, is almost perfect, save for the large part of the tail, which was inclosed in a protuberance from the main block, and the piece inclosing it doubtless is still to be found in the wash where the scattered pieces were secured. Nearly every bone is in natural articulation, the phalanges for the most part being scattered, some lost, others doubtless yet hidden in the matrix. Furthermore, the bones had suffered almost no distortion or compression. The skeleton was fossilized in a prone position and was somewhat depressed from its own weight. The bones, however, inclosed in the hard, dark, red clay, are rather soft, with a thin, white, cuticular, calcareous layer. So far as possible the skeleton has been laid bare, but no attempt has been made to separate any of the bones, nor could they be separated with safety. The occipital region of the skull, lying above the clavicular girdle, is inaccessible, as are also the posterior ribs, inclosed between the close-lying porrected femora and the vertebral column. Both hind legs are directed forward nearly parallel to the vertebral axis, the feet pulled slightly away from the tibiae and fibulae. The right fore leg also lies close by the side of the body, the hand bones intermingled with the corresponding foot bones. The left fore leg is directed forward. The pectoral girdle lies closely in position, the left side pressed back a trifle, and the pelvic girdle is almost perfectly in place. The skeleton, to the sixth caudal vertebra, measures twenty-one inches. Because of this natural position of the skeleton it has been a matter of little difficulty to figure it in a restored position, the limb bones of other specimens furnishing the proper views in the changed positions. A full description of the form, with detailed figures, will be published later. The figure here given, made with care by myself, will furnish the most of the chief characters of the genus. Those parts unknown or imperfectly known are represented by uniform shading. That the numbers of the phalanges as figured are correct

is practically certain because of the like numbers determined by me in *Limnoscelis;* that the toes were slender is evident from several isolated, unplaceable distal phalanges in the matrix. That the tail could hardly have been longer than is represented, perhaps not as long, is indicated by the taper of the six proximal vertebrae preserved in position, folded down, like a dog's tail, to the extremity of the ischia. Two distal tarsals cannot be seen as covered by the metatarsals; and the carpals cannot be clearly made out.

As a whole *Seymouria* stands lowest in rank among known reptiles, approaching in many ways the contemporary amphibians. This is indicated by the structure of the posterior cranial region, by the extraordinary amphibian ear-notch, by the primitive structure of the vertebral centra, as shown in *Desmospondylus*, by the long, free, caudal ribs, by the possession of a single sacral vertebra, and by the very amphibian-like limb bones and girdles. Indeed, so far as the characters are shown in the figure, there is not a single thing to differentiate the form from an amphibian, unless it be the apparent absence of the cleithrum. Unfortunately the mutilation of the bone in the cranial table prevents the corroboration of the temporal sutures as determined by Broili; but I doubt not that Broili's determinations are correct, showing all the bones found in the temnospondylous amphibians and in similar arrangement, some of which have never been detected in other reptiles. The palate, also, as I make it out, is different from that of other known reptiles, though distinctly reptilian in structure. The pectoral and pelvic girdles are absolutely indistinguishable from those of the contemporary amphibians, save by the more posteriorly directed ilia and the absence of the cleithra, and both of these characters may and probably will yet be found in the temnospondyls.

The suture between the scapula and coracoid is very distinct, quite in the position I have found it in other Texas reptiles and amphibians; and the coracoid is composed evidently of but a single element, the posterior element, the so-called coracoid, remaining cartilaginous through life, as was also the case in *Varanosaurus*. It is because of these facts, observed in several forms, that I am quite convinced the coracoid as preserved corresponds identically

with the coracoid of the lacertilia and rhynchocephalia, that is, it is the true coracoid, and not the procoracoid. To assume that the coracoid of these animals has been replaced *in toto* by another bone, leaving only the supracoracoid foramen, which alone has remained permanent, the bone surrounding it disappearing to give place to another represented by cartilage, in some of the forms at least, and far back of the foramen, is beyond the limits of my credulity, whatever it may be for others.

In the structure of the skeleton of *Seymouria* nothing is more conspicuous than the extraordinary development of the arches of the dorsal vertebrae, forming almost a carapacial protection for the body. That the animal was crawling in habit there would seem to be no doubt, notwithstanding the position in which the hind legs were found—a position quite the same as that of the type specimen of *Limnoscelis*. No indications of ventral ribs are preserved and I think it may be said with absolute certainty that the creature possessed none in life. On the other hand, scattered through the matrix were numerous small flakes of bone, always isolated. They may indicate osseous scutes. The teeth of the creature are long and slender, utterly useless for the seizure and retention of large prey. I think it very probable indeed that its food consisted in large part, probably wholly, of the smaller invertebrates, cockroaches, land mollusks, worms, etc., and that in habit *Seymouria* was not unlike the modern land salamanders, slow and sluggish in movement, hiding under fallen and decaying vegetation in low and damp places.

The American cotylosaurs, more especially the Diadectidae, Limnoscelidae, and Seymouriidae, show marked resemblances in many ways to the contemporary amphibians, in their short legs, broad feet, enormous humeral entocondyle, digital fossa of the femur, pronounced adductor crest, as well as girdles; but I do not believe that these resemblances were so much the result of phylogeny as of convergent evolution, the adaptation to similar environmental conditions and similar habits. *Araeoscelis* alone among the known American Permian reptiles had a very slender body and delicate, slender legs, adapted for climbing, or at least for swift-moving upland habits. That there were many other

reptiles in Permian times of similar structure and habits is evidenced by *Kadaliosaurus,* among others. And all these must have come from a common amphibian ancestry, so far back in Carboniferous times as to permit great structural diversity among both the reptiles and the temnospondyls in early Permian times, too great to warrant the assumption that all similar characters in the two classes are the result of heredity.

The relationships of *Seymouria* are, on the one hand, closest with *Limnoscelis*, on the other with *Labidosaurus*, but differing so markedly from both as to merit a co-ordinate independent position for the genus, which I prefer to call of family value—the Seymouriidae.

GEOLOGIC AND PETROGRAPHIC NOTES ON THE REGION ABOUT CAICARA, VENEZUELA[1]

T. A. BENDRAT
Turners Falls, Massachusetts

In the winter of 1908–9, the writer carried on some independent studies along petrographic and geologic lines, in the interior of Venezuela, choosing for his field of investigation the region immediately west of the so-called "El Caura District," at the famous bend of the Orinoco, and mapping an area of 1,400 sq. km., which was hitherto very little known. While the general results of this survey have been summed up elsewhere,[2] it is on the main geologic and petrographic features of the region that the writer wishes to offer the following observations.

GEOLOGIC STRUCTURE

1. THE BED ROCK

The bed rock consists of a series of granites and gneisses which, wherever they come to the surface, show a predominance of the gneiss over the granite. These granites and gneisses rise from the bottom of the Orinoco channel; constitute the base of many of the islands; are exposed in the banks of the river, particularly in the dry season; and back from the river form the bulk of the "Cerros." These cerros are hills and small mountains which rise above the plain of the sabana. In general they increase in height in proportion to increasing distance from the Orinoco, and may be regarded as outliers of the Guiana mountain system lying to the south. These cerros are probably to be considered as portions of the great series of granites and gneisses which have most effectively resisted disintegration, partly because a skeleton of numer-

[1] The writer desires to express at this place his high obligations to Professor B. K. Emerson of Amherst College who was kind enough to have the petrographic microscopes of Smith College, Northampton, Mass., placed as his disposal.

[2] Petermann's *Geogr. Mitteilungen* (1910), Bd. 56, v; *Geographen Kalender* (1909), 221.

ous veins and dikes cutting each other in all possible directions traverses them.

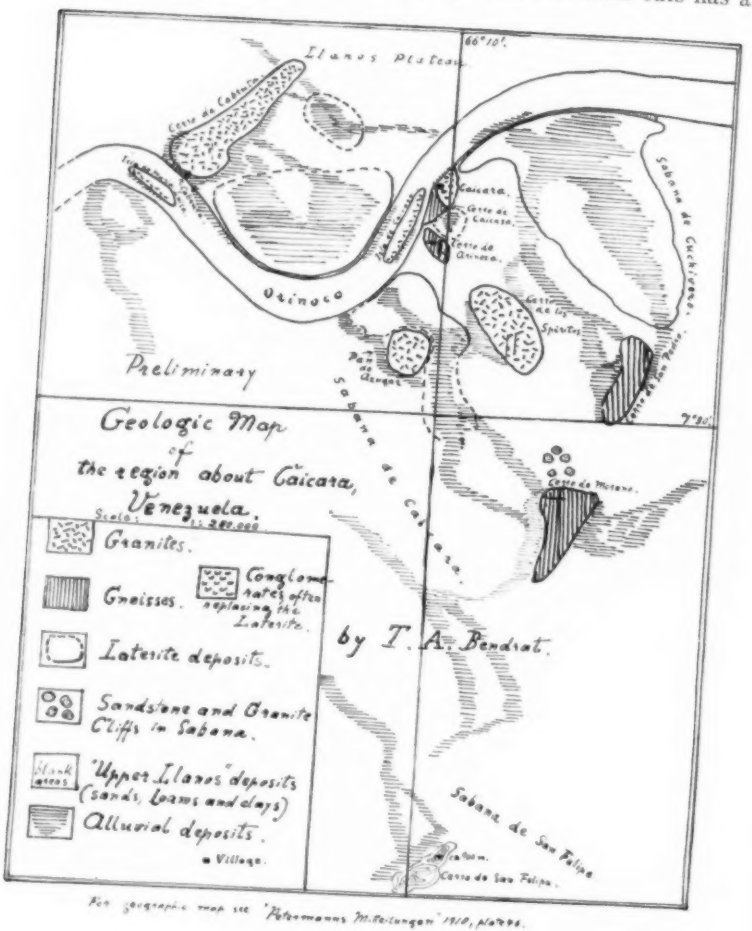
An extended survey of the shores of Isla de Caicara, opposite the village of Caicara, showed that the bed rock of this island is a medium-grained granite of comparatively firm texture, which is drab colored in fresh breaks, but which weathers to a purplish tint. This rock shows cleavage planes extending north and south, and east and west.

The cliffs exposed on the Caicara side of the stream by the falling of the Orinoco during the dry season consist of medium to fine-grained gneiss, whose laminations run either N.N.E.–S.S.W., or E.N.E.–W.S.W. Quartz veins, varying in thickness from three to five inches, cut the gneiss in a general N.W.–S.E. direction. It was on the surface of one of these rocks, about 1 km. north of Caicara, that the writer discovered what, considering the latitude, would seem a very curious phenomenon. This consisted of three grooves, about five inches long and one-eighth inch deep, which run perfectly straight, one N. 80° E., and the two other S. 80° E. They show a striking resemblance to glacial striae, but this does not exclude the possibility that they may have been produced by man, as in close proximity a series of the so-called "petroglyphics" was found, the grooves of which, however, were considerably deeper and wider. The surfaces of the rocks on which the grooves were observed were considerably smoothed, as were the rocks of the banks of the Orinoco, but this might be due to the effects of the currents.

The distribution of the granite and the gneiss in the hills and ridges north of Cabruta and south and southeast of Caicara also plainly reveals the prevalence of the gneiss over the granite, for, with the exception of Cerro de Cabruta, north of the Orinoco, and Cerro de los Spiritos, the lower portion of Cerro de Arinoza, and possibly the whole of Pan de Azugar, all the cerros consist of gneiss (see map, Fig. 1).

The Cerro de Cabruta, rising abruptly at its southwestern terminus from the waters of the Orinoco to a height of about 290 meters above sea-level, trends, for a distance of about 12 km., in a N.E. direction, and gradually falls off toward the llano plateau.

The cerro is entirely made up of a coarse-grained feldspathic granite, which weathers to a dull reddish purple, and in fresh cuts has a



For geographic map see "Petermanns Mitteilungen" 1910, plate 6.

FIG. 1

yellowish-white color. The yellow predominates over the white. Toward the top, the granite becomes more and more quartzose,

while at the same time the quartz veins become more and more frequent. Some of these quartz veins strike parallel to the general cleavage planes, that is N. and S., while others run E. and W., and W.N.W. and E.S.E. The disintegration of the granite by means of exfoliation was most strikingly exhibited on the top. At one place a dike of gray to bluish-white quartz cut the granite in a direction N.N.W. and S.S.E., which most probably determined the initial direction of the southwestern spur of the cerro. Along the line of contact, the granite seems to have become changed locally into gneiss with lamination in a direction N.N.W. and S.S.E. This was, however, the only instance of a gneissic phase observed in the bulk of the granite.

Of the series of cerros on the southeast side of the Orinoco, the Cerro de Caicara comes first and lies immediately south of the village of Caicara. It rises to a height of 127 meters above sea-level and extends about 2 km. to the south, along the bank of the stream. It consists entirely of a more or less fine-grained gneiss of light color, but on weathering becomes a dark purple. At different levels the gneiss is highly charged with various grades of iron oxide, which exhibit beautiful shades of color, ranging from tan through ochre yellow to a dark bloody red. The direction of lamination is, in most cases, parallel to the general strike of the rocks.

About 3 km. south of Caicara lies the Cerro de Arinoza, which attains a height of 146 meters, while its foot is 71 meters above sea-level. Only the lowest levels of this hill consist of a close-grained quartzose granite such as was encountered in the Cerro de Cabruta. The structure of this granite is in places pegmatitic and the cleavage planes run N. and S., and E. and W., as do quartz and pegmatite veins. Higher up in the slope, however, the granite yields to a medium-grained gneiss, the laminations of which run S. 20° E. and dip at an angle of 27° to the northeast.

The Cerro de los Spiritos is situated about 5 km. east of Pan de Azugar, and nearly 8 km. S.S.E. of the village of Caicara. About 200 feet high, it trends in a general N.W.–S.E. direction for over 5 km. With a possible exception of Pan de Azugar, as indicated above, it is the only cerro southeast of the Orinoco within

the scope of the region under discussion which is entirely composed of granite. It is of the coarse-grained feldspathic type and exhibits joints which run pronouncedly N. and S., E. and W., and N.W.–S.E., and in no other direction. The backbone of the hill is a quartz dike from 3 to 5 feet wide, which runs along the southwestern flank of the hill in a N.W.–S.E. direction. Assays made of samples from this dike reveal traces of gold. Other quartz dikes run parallel to this one as well as at right angles to it, while near the top a dike of pinkish felsite about 2 feet thick and running E.–W. stands out prominently from the surrounding coarse-grained granite, which assumes a rather hornblendic aspect in the upper levels. The flanks of the cerro, where slopes are gentle, and only occasionally steep, are dissected by gullies and ravines running parallel to the main quartz dikes in the main.

About 26 km. S.S.E. of Caicara the Cerro de Morano rises above the plain of the sabana in two distinct knobs which have heights of 375 and 396 meters respectively above sea-level. Its topographic outlines seem to be determined by two main quartz dikes, the more prominent one running N. and S., constituting the backbone of the cerro. Approaching the cerro from the north, one encounters knobs and cliffs emerging from the sabana, which consist of purplish weathering, coarse-grained feldspathic granite, occasionally highly charged with iron oxides, and at places overlain by limited (in size) "banks" of ferruginous coarse-grained sandstone. But the bulk of the cerro itself is made up of hornblende gneiss, which ranges from fine to coarse grained. The average direction of lamination is N. and S., and N.W. and S.E.

2. THE SABANA DEPOSITS

In dealing with the deposits of the sabana, above which rise the isolated cerros just described, one must distinguish between the so-called "Laterite" deposit and what Dr. S. Passarge terms "Upper Llanos" deposits.

1. *The "Laterite" deposit.*—This deposit is a concentration of iron oxide in a series of more or less fine and soft clays of a light gray color. Deposits of this class have been found by Dr. S. Passarge along the banks of the Cuchivero as well as the Caura,

and by the writer overlying the gneisses on the banks of the Orinoco. As long as the deposit is under water or is still charged with water after the streams have fallen during the dry season, it is very pliable; but as soon as it becomes dehydrated, it turns extremely hard and takes on the aspect of a clay ironstone. It has been

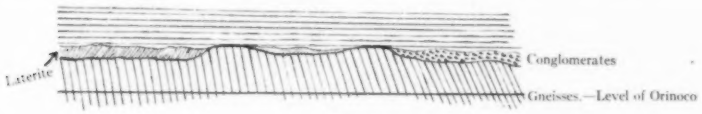


FIG. 2

called "Laterite," and likened to the German "Zellinger Braun-eisenstein." The only true laterite portions form the upper part of the clayey mass or are segregated from this. The clays are in many places marbled by a more or less intense red. The deposit directly and unconformably overlies the gneissic or granitic bed rock. The deposit is not continuous and is frequently replaced by a conglomerate, cemented by iron oxide (see Fig. 2). It occurs inland as well as along the Orinoco.

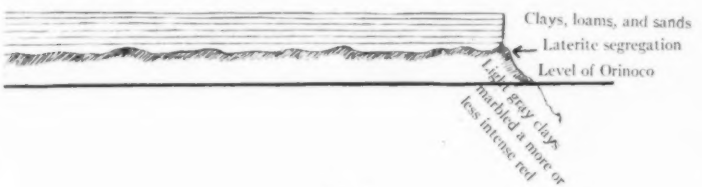


FIG. 3

2. *The Upper Llanos deposits.*—The Upper Llanos deposits which, as a rule, unconformably overlie the "laterite," wherever they have not been removed by erosion, may be said to consist of the following three members: (1) A whitish or yellowish clay which exhibits yellowish-brown cell structure, rich in iron; (2) loams of various nature; (3) sands of different fineness and color.

Their interrelation changes with the locality and so do their respective horizons. They constitute the upper portions of the islands, as well as the upper terraces at an elevation of 50 feet, approximately, above the average level of the lower terraces, and

finally, the sabana itself. They lodge between the rocks of the granites and gneisses, wherever these come to the surface, filling in interspaces. The loam becomes very pliable and soft during the rainy season, so much so as to allow mud turtles to plow furrows from half a foot to a foot deep in it. Local torrents sometimes carve channels down to the underlying laterite. The walls of these channels become extremely indurated during the dry season, rendering traveling across the sabana under such conditions laborious, especially where there are no roads or paths available.

PETROGRAPHY OF THE GRANITES AND GNEISSES THAT CONSTITUTE THE CERROS IN THE SABANA ABOUT CAICARA

1. THE GRANITES

The granites of the region under consideration comprise those of the Cerro de Cabruta, the Cerro de los Spiritos, and those at the base of the Cerro de Arinoza. A detailed microscopical study of specimens taken from different levels shows that in all three cerros the type of granite is essentially the same. This statement, however, has to be modified in so far that, at one end of this elliptic area, the granite is decidedly leukocratic while at the other it is melanocratic. While the Cerro de Cabruta consists of a more or less pronounced quartzose granite in its upper levels and its top, the Cerro de los Spiritos reveals a decided predominance of hornblende in the granite of its top.

Though described here in general terms as granite, this rock is more correctly designated as quartz monzonite porphyry. Its ground mass is made up of more or less angular or subangular crystals of quartz and feldspar through which the leading minerals are sprinkled as phenocrysts. These phenocrysts are quartz, which sometimes predominates over the feldspars, occasional orthoclase associated with, or replaced by, microcline, the soda-lime and lime-soda feldspars albite and labradorite, and finally biotite, associated with or entirely replaced by hornblende.

Quite a number of quartz and feldspar phenocrysts show enlargement by secondary growth as revealed by zonal extinction or by a more or less faint ring of dark material, apparently representing a coating of the original grain.

The frequent occurrence of a micro-pegmatitic texture suggests conditions in the original magma that favored a simultaneous crystallization of the quartz and feldspar.

Of the feldspathic minerals those of the soda-lime group apparently prevail over the orthoclase (not so much over the microcline), and among them labradorite is the one most frequently found.

The biotite occurs in lath-shaped crystals and in shreds and flakes, the amphibole mostly with prismatic outlines, and only occasionally in cross-sections. It was in such a cross-section that an intergrowth of biotite and amphibole was observed, the former penetrating the latter, clearly demonstrating their contemporaneous development. Apatite and titanite occur as inclusions in the biotite, while the amphibole contains apatite and magnetite. Microlites of biotite and apatite needles have been observed in feldspar, while quartz carries magnetite, apatite, and occasionally zircon. In cavities within the quartz liquid inclusions are sometimes present. Titanite is also found free in wedge-shaped crystals, and considerable garnet, in more or less complete crystals, occurs. Secondary minerals are calcite, which might have been derived from some of the feldspars, and chlorite, which apparently has come from the biotite.

Wavy extinction in quartz and feldspar; bending, breaking, and slicing of feldspar and biotite; granulation of feldspar and occasionally of quartz; and the complete crushing of titanite crystals strongly suggest dynamic stress and shearing.

The occurrence of looped grains of orthoclase, and the more or less advanced decomposition and the decoloration of a considerable percentage of the biotite indicate katamorphic action, most probably by descending waters, while the secondary growth of minerals, involving zonal structure, and the formation of veinlets, where crystals were broken, tell rather of the anamorphic activity of ascending solutions.

2. THE GNEISSES

The gneisses of the cerros in the sabana of Caicara comprise those of the Cerro de Caicara, Cerro de Arinoza, with the exception of its base, and those of the Cerro de Morano. A micro-

scopic analysis of thin sections of samples taken from all levels of these cerros, and a comparison of their composition, texture, and fabric, tend to lend much weight to the assumption that the gneiss throughout belongs to one and the same unit, as it was one and the same type of rock we had to deal with in the granites. This statement is, however, not intended to exclude the possibility of local phases representing gradation and variation.

Like the granite, the gneiss is porphyritic. In a ground-mass commonly of angular or subangular grains of quartz, with rather fringed and dentated outlines, and of feldspars, especially microcline and plagioclase, which usually are arranged with their longer diameters parallel or slightly inclined to the plane of rock-cleavage, are imbedded phenocrysts of pegmatite, microcline, albite, labradorite, and biotite. All of these minerals, with the exception of the biotite, are more or less allotriomorphic. Microcline seems to take the place of orthoclase to a great extent, wherever the latter is not intergrown with quartz, and we might say that the predominance of microcline and pegmatite constitutes one of the main features of this gneiss. Another feature is the frequent occurrence of crossed lamellae in the plagioclases and a marked tendency to form rather broad lamellae.

Of the feldspar and quartz the former is in excess. Among the ferro-magnesian minerals, biotite, in phenocrysts of lath-shaped form and in flakes, seems to be almost the only representative. Hornblende is very seldom encountered, though in one instance it was found intergrown with biotite.

Of accessory minerals an occasional crystal of pyroxene is encountered, while magnetite and hematite are more frequently met with. Garnets are not uncommon and wherever they occur they are idiomorphic. Chlorite is present most probably as a decomposition product from biotite and hornblende.

As regards inclusions in the different minerals, magnetite occurs in feldspars, arranged more or less parallel to the plane of parting, and in quartz where it occurs as a cloudy matter and in dendrites. Of other inclusions may be mentioned zircon, apatite, titanite, and tourmaline (?) in quartz, and very fine glassy particles in the plagioclases.

The gneisses, even more than the granites, exhibit overwhelming evidence of metamorphism, during, as well as since, their formation. Among the evidences of stress and shearing, may be mentioned: The wavy extinction in quartz and feldspar grains; the bending of biotite; the differential bending and anastomosing of the lamellae of feldspars; cracks and fractures parallel or normal to the plane of parting in biotite; the slicing of crystals of pegmatite and microcline; the breaking of crystals of feldspar and biotite and displacement of the broken parts by miniature faulting; a granulation zone about grains of pegmatite.

A gneissoid texture is given to the rock by the more or less parallel arrangement of the longer axes of the minerals to the plane of schistosity of the rock.

The dissolving agency of descending waters is shown by the schiller structure of some plagioclases, the cloudy appearance of other feldspars, and the decomposition of some of the magnetite, biotite, and hornblende. The anamorphic agency of ascending waters is indicated by secondary growth of quartz, plagioclase, and biotite; by the cementing of cracks and fissures, and by the formation of veinlets by segregation from the same mineral or by infiltration from some other source.

3. THE VEINS AND DIKES IN THE GRANITES AND GNEISSES

The writer profoundly regrets that he did not have time to examine more closely the veins and dikes of the cerros about Caicara, as a more detailed and special study of these veins and dikes most probably would have brought out different sets, as indicated by uniformity of strike and dip and of composition, and might have shown something in relation to the nature and the succession of the dynamic movements which the gneisses and the granites, individually or together, have undergone.

While the writer is far from attaching any special significance to it and deducing any particular law of succession from it, because of the limited material on hand, it is nevertheless a peculiar fact that all of the more prominent quartz veins and dikes encountered have a strike magnetic N.–S., while all the pegmatite veins and dikes strike E.–W. Near the summit of Cerro de Morano a vein

of fine-grained amphibolitic gneiss, varying in thickness from two to three feet, strikes N.–S. A few feet below the top of Cerro de los Spiritos a felsite vein about one foot thick extends E.–W. and stands two feet above the surrounding coarse-grained granite, so that from a distance it has the appearance of the remnant of a brick wall. A microscopic investigation showed that its main constituents are quartz and plagioclase in nearly equal proportions, while some dark-brown and yellow biotite occurs as an accessory mineral. A microscopical examination of the N.–S. quartz veins shows that they are made up of very small grains of quartz with dentated margins in most cases and most intricately interlocked; of bronze-brown to dark-green amphibole in irregular patches; occasional tourmaline in radiate aggregates; some garnets, and some magnetite.

In concluding, the writer wishes to remark that it would be of great interest to ascertain the geologic and petrographic nature of other outliers in those waste plains that approach the Orinoco from the S. and from the E., as well as the character of the rocks that make up the bulk of the Guiana mountain system, in order to bring out facts that would bear on the relations of those cerros to this, most probably, Archaean center.

THE AGE OF THE TYPE EXPOSURES OF THE LAFAYETTE FORMATION[1]

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Johns Hopkins University, Baltimore

The following brief communication is devoted to showing the Eocene age of the type-sections of the Lafayette formation in Lafayette County, Mississippi, and also at certain additional localities in northern Mississippi and southwestern Tennessee where fossil plants have been collected by the writer.

The term Lafayette formation has come in late years to be widely used by American geologists and the volume of literature devoted to its consideration is by no means inconsiderable.

It is not necessary in the present connection to recite the history of the study of the deposits which have been referred to the Lafayette. It will suffice to recall that the name was proposed by Hilgard[2] in 1891 for those deposits so elaborately described in his *Geology of Mississippi*[3] as the Orange Sands, and typically developed in Lafayette County. Chief among the students of the Lafayette was W J McGee who extended their occurrence from Mississippi to Pennsylvania on the one hand and as far as Texas on the other.[4]

The writer is not concerned in the present brief note with those deposits in the various Atlantic and Gulf states which have been referred to the Lafayette formation by different geologists. In certain limited areas, however, reliable data have been obtained which may appropriately be announced in the present connection. Thus in the vicinity of Columbus, Georgia, materials classed as Lafayette are Cretaceous in age. Other materials referred to

[1] Published by permission of the Director of the U.S. Geological Survey.

[2] Hilgard, *Amer. Geol.*, VIII (1891), 130.

[3] Hilgard, *Rept. on Geol. and Agr. of Miss.* (1860), 5–46 (the name Orange Sand was that of Safford, 1856).

[4] McGee, *U.S. Geol. Surv., 12th Ann. Rept.*, Part I (1891), 347–521.

the Lafayette in the vicinity of Glen Allen, Fayette County, Alabama, should be assigned to the Tuscaloosa. In several sections across the Cretaceous of northeastern Mississippi in the latitude of Tupelo and Booneville, the Lafayette cover in all observed exposures resolves itself into the weathered beds of the Cretaceous. The same statement is true in the writer's judgment of the great cut near Cypress, Tennessee, on the Southern Railway. This whole section was included in the Orange Sand by Hilgard and figured diagrammatically on p. 16 of his *Geology of Mississippi*, though it was subsequently shown that the basal part was Ripley Cretaceous. The writer visited this exposure during the past season and failed to see any reason for not including it all in the Ripley. Furthermore, at a large number of localities throughout the Mississippi embayment area, Pleistocene terrace deposits have been referred to the Lafayette formation.

During 1910 it was the writer's privilege to spend considerable time in the collection of fossil plants in Lafayette County, Mississippi, and northward as far as Cairo, Illinois. It might be added parenthetically that five previous field seasons spent, for the most part, along the inner margin of the coastal plain from New Jersey to Mississippi have afforded considerable opportunity for observing the so-called Lafayette.

It has been commonly supposed for some years back that the Lafayette formation of Mississippi and western Tennessee was not a unit, since remains of the so-called eolignitic flora have been reported from time to time as occurring in it at numerous localities. It has been assumed, however, that these plants came from the Eocene clays beneath overlying Lafayette materials. While at most of the localities visited during 1910 the Wilcox clays with leaf impressions are overlain by reddish sands of no considerable or uniform thickness, this is not always the case, as is well shown by one of the exposures along the Illinois Central Railroad just north of Oxford, Miss. The outcrops in these railroad cuts, a number of views of which, from photographs by the writer, are here reproduced, were the type-sections of Hilgard's Orange Sands and Lafayette. Here as at every other locality where the writer collected plant fossils in Lafayette and Marshall counties, Missis-

sippi, and in Fayette and Hardeman counties, Tennessee, there is no unconformity between the Eocene Wilcox leaf beds and the supposed Lafayette if the latter be restricted to the few upper feet of weathered sands.

In order that there might be no room for doubt but that the Oxford exposures furnish the type-sections for the Lafayette, Dr. McGee has kindly prepared the following letter covering this point, at the request of Dr. T. Wayland Vaughan, geologist in charge of the coastal plain investigation for the U.S. Geological Survey:

[Copy]

March 1, 1911

MY DEAR DOCTOR VAUGHAN: In further reply to your oral inquiry: On looking up the records, I find it clear that the type locality in Lafayette County, Mississippi, from which the Lafayette formation received its current designation, is Oxford, the site of the state institution of learning with which Dr. Hilgard was long and honorably connected; and that the type-section is the exposure in the Illinois Central Railway cut at Oxford shown by Dr. Hilgard in *Geology and Agriculture of Mississippi* (1860), p. 6, in the drawing reproduced by me in "The Lafayette Formation" (*Twelfth Annual Report, U.S. Geological Survey*, Fig. 58, p. 457). This section was in good condition for examination in 1891, and was re-examined as the type-section by Dr. Hilgard, the late Dr. J. M. Safford, Dr. Eugene A. Smith, Dr. Joseph A. Holmes, Professor Lester F. Ward, Mr. Robert T. Hill, and myself, jointly, and was still in good condition in February, 1910, when re-examined by Dr. E. N. Lowe, state geologist, and myself, as the type-section of the formation.

Yours sincerely,

(*Signed*) W J MCGEE

In the exposures at Oxford the deposits are a unit with every gradation from unweathered materials below to oxidized and more or less ferruginous sands above. Nowhere in this region is there a line of unconformity or a pebble bed to mark the supposed time interval extending from the early Eocene to the Pliocene. The change in color of the materials when marked at all is at varying levels and is due apparently to the depth to which the ferric oxide in the sands has been dehydrated. A quotation from McGee's longer paper on the Lafayette will make it clear that he did not recognize any unconformity between the leaf-bearing clays now ascertained to be Eocene, and the overlying sands. On pp. 458, 459, he says:

Several competent geologists familiar with the Lignitic in Mississippi, Alabama, Tennessee, and Arkansas are disposed to refer the leaf bearing clays to that formation on the ground of lithologic resemblance. If this reference be just, then the thickness of the formation may be less than that assigned by Hilgard at Oxford and Johnson at Holly Springs, and even the exposed thickness at La Grange may include an unknown amount of the protean Lignitic deposits though no demarcation has ever been found.

At one of the Oxford exposures, previously mentioned, the Eocene clay lens is almost at the surface and overlies "typical

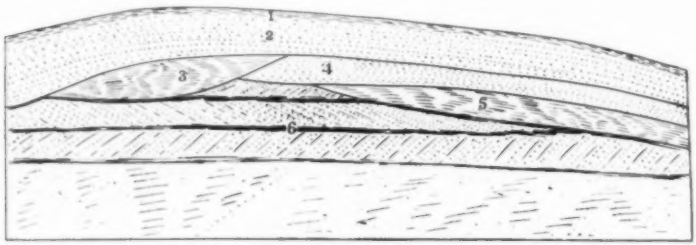

FIG. 1.—Diagram of exposure furnishing fossil leaves in the type area

Lafayette materials." This section is shown diagrammatically in Fig. 1, and may be described as follows:

SECTION EAST OF I.C.R.R. ½ MILE NORTH OF OXFORD STATION

No. 1.	Brown loam	1– 2 ft.
2.	Rather coarse brown stratified sand	4– 6 "
3.	Lens of gray to white siliceous clay, carrying abundant leaf impressions	0– 5 "
4.	Stratified orange sand	2– 3 "
5.	Lens of gray siliceous clay, with poorly preserved leaf impressions	0– 4 "
6.	Coarse brown cross-bedded sands separated by ferruginous indurated bands 1 to 3 inches in thickness. Replaced horizontally by pinkish or grayish buff finer sands	10–12 "

Fig. 2 is from a photograph of this outcrop, the fossil plants having come from near the top of the exposure at the "nose" just below the small tree shown in the center of the picture. The clays at this point are siliceous and do not contain an extensive flora, and the collections consist largely of the abundant remains

FIG. 2.—View showing the plant locality one-half mile north of the depot, Oxford, Miss.

FIG. 3.—View showing ferruginous cross-bedded sands just north of the plant locality.

of a *Panax*-like form and a fan palm identical with what Lesquereux called *Sabal grayana*. The latter was originally described from the Lignitic[1] and the former, while apparently new, is closely allied to early Tertiary forms from southern Europe. Few forms abundantly represented may be taken as indicating that the plants were not drifted into the basin of sedimentation from a

FIG. 4.—View showing the type-section of the Lafayette just south of the depot at Oxford, Miss.

distance but that they grew in the immediate vicinity and that the shallow waters of the Mississippi gulf in Wilcox time were not marine in this latitude. This is also indicated by the impressions of Unios in this same clay lens. At some of the other plant localities visited, as for example that at Holly Springs and Early Grove in Mississippi and at Grand Junction and La Grange in Tennessee, all of which are specific Lafayette localities of McGee, the fossil floras are more varied and consist of species of Cercis, Laurus,

[1] Lesquereux, *Proc. Amer. Philos. Soc.*, XIII (1869), 412, Pl. XIV, Figs. 4–6.

Ceanothus, Banksia, Dryophyllum, Sabal, Ficus, Dalbergia, Nerium, Terminalia, and perhaps one hundred additional forms, including even flowers and Acacia-like pods, all unquestionably of Eocene age and closely paralleling the Eocene floras of southern Europe. Furthermore these Eocene forms are all of them contained in beds absolutely inseparable from the surficial more or less

FIG. 5.—View showing the character of the materials referred to the Lafayette, one mile north of depot, Oxford, Miss.

oxidized sand which a forlorn hope might lead one to retain as representing the Lafayette.

It must not be supposed that there are no surficial deposits in this general region. The present communication is merely intended to show that certain fossiliferous sections including the type-section of the Lafayette and probably all of the Lafayette in Lafayette County, Mississippi, are of Wilcox Eocene age. A possible objection to the foregoing conclusion might be that these floras upon which it is in part based are really Lafayette floras. This is

utterly impossible. In the first place it would mean that the balance of the leaf-bearing Wilcox is of Lafayette age since the two have a considerable number of species in common. McGee seems to have had some premonition that the fossil plants when studied would not bear out his conclusions since he writes:

> The testimony of the plant fossils is of course only suggestive; for not only is the identification incomplete, but there are thus far no means of comparing the stages in evolution of plant life in the upper Missouri and Rocky Mountain regions and the lower Mississippi region respectively; it can only be said that in the one region the geography was repeatedly revolutionized in such way as greatly to modify climatal conditions, while in the other the geography has undergone only minor changes of such character as not to modify climate, so that the flora has undoubtedly persisted in the remarkable fashion suggested by the present existence of Laramie or Lafayette plants in Louisiana.

This may be dismissed as a specious argument, for it can readily be shown that no post-Miocene floras of the northern hemisphere contain the types which are prominent in this flora. On the other hand the climatic changes have been considerable, even the Pliocene flora in this area of supposed slight change containing species no longer present in the region or even in North America.

In the second place the flora is closely allied to European floras of unquestioned Eocene age, more especially to that described by Saporta from France, and in its *tout ensemble* it denotes climatic conditions very different from those which could possibly have existed in Lafayette time.

There are high-level gravels in northeastern Mississippi and in northern Tennessee and beneath the loess along the Mississippi bottom ("delta") as well as at various points along the Atlantic Piedmont border. Whether these are river gravels of various ages or whether we are dealing with the remnants of a high-level early Pleistocene sea terrace is not clear, although a combination of the two is the probable solution.

THE RIPPLES OF THE BEDFORD AND BEREA FORMATIONS OF CENTRAL AND SOUTHERN OHIO, WITH NOTES ON THE PALEOGEOGRAPHY OF THAT EPOCH[1]

JESSE E. HYDE
Columbia University

THE BEDFORD AND BEREA FORMATIONS

The Bedford and Berea formations are respectively the lowest and second lowest members of the Waverly series of Ohio. They were formed either at the close of the Devonian or at the beginning of the Mississippian period. They can be traced continuously across the state along the outcrop, from the Pennsylvania line on the northeast to the Ohio River on the south and over broad areas under cover to the eastward. The Bedford is almost entirely a shale formation usually about 100 feet thick; the Berea is a sandstone roughly from 20 to 150 feet thick.

In northern Ohio, the Bedford is largely an argillaceous shale with sandstones present locally, the Berea a coarse, feldspathic sandstone; the two are separated by an erosion plane.[2] In southern Ohio the Bedford consists of interbedded sandstones and shales, the former sometimes greatly in excess, the Berea of similar sandstones with limited quantities of shale. The sandstones in both are fine grained and of exactly the same type while between the two there is a transition zone. It is now becoming evident that the geological history of these beds has been quite different on opposite sides of the state, although the relation of the succession in one area to that in the other is not yet known. The Berea of southern Ohio is only a phase of the Bedford of the same region, while that of northern Ohio is wholly distinct from the Bedford and probably from the southern Ohio Berea. However, as a sandstone formation, it is continuous across the state.

[1] Published by permission of the State Geologist of Ohio.

[2] Charles S. Prosser, manuscript.

In the area under immediate consideration, central and southern Ohio, the Bedford is from 90 to 100 feet thick, the Berea from 5 to 40 feet thick. In Scioto County on the Ohio large amounts of sandstone are found in the Bedford, but this diminishes to the northward so that there is much more shale in Pike and Ross counties, while in Franklin County there is practically no sandstone, except in the upper 10 feet where very thin layers appear in profusion. In Pike and Ross counties the sandstones are frequently limy. When present, the sandstones are in beds from a few inches to two or three feet thick, but the "shale" beds intervening between such beds, often several feet thick, are largely made up of very thin, hard, platy sandstones of which there may be 12 or 18 in a foot.

Exactly the same type of sandstone is found in the Berea of central and southern Ohio as in the Bedford, except that the lime disappears. In fact the Berea is distinguished from the Bedford of the region almost solely by the rather abrupt diminution in the amount of "shale." These shale beds are found to some extent in the lower part of the Berea and, just as in the Bedford, they carry the numerous, thin, platy sandstones. In other words, the lithological change from the Bedford to the Berea was almost wholly one of amount and not of kind of material.

THE OCCURRENCE OF THE RIPPLES

Ripples are seldom noted in the lower part of the Bedford. In southern Ohio they appear rather gradually near the middle, and throughout the upper half of the Bedford and most of the Berea they are present, sometimes in astonishing abundance. The surface of each of the very thin lamellae of sandstone is rippled, as well as of the thicker beds. In central Ohio they appear first in the thin sandstones at the top of the Bedford, but are confined almost wholly to the Berea. In central Ohio and as far south as Pike County, the ripples gradually disappear in the upper part of the Berea and they may be absent entirely in the upper 10 or 15 feet, which also may become slightly coarser.

Many localities can be found, especially in Pike County, where the streams have cut into the Berea grit or the upper part of the

Bedford, and flow for some distance over a rock floor composed of the strata of these formations. Bed after bed is exposed in descending order, each with a beautifully rippled upper surface, and where the stream cuts through one of the "shaly" beds as many as 12 or 18 may be encountered in a vertical thickness of one foot, each ripple-marked. The parallelism of these ripples is most strikingly shown where the gradient is such that the stream descends gently across such a series, each of the surfaces forming the creek bed for a distance, to be superseded presently by the next layer lower down.

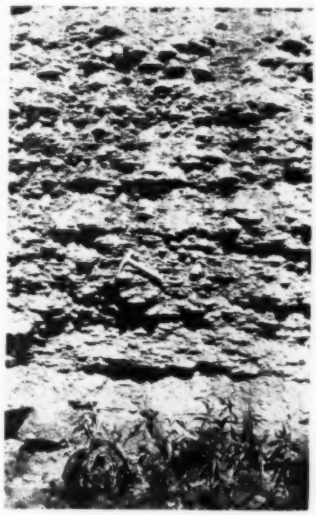

FIG. 1.—A portion of the upper part of the Bedford in the D.T. and I.R.R., cut southeast of Waverly, showing the many thin platy sandstones which largely make up the shaly portions of the formation. Each is rippled. Sometimes only the crests of the ripples are preserved as a series of lenses. The thicker sandstones are not present in this outcrop.

REVIEW OF PREVIOUS WORK

E. B. Andrews in 1870 first noted that the ripple-marks in the vicinity of Buena Vista trend in a northwest-southeasterly direction.[1] The formation in which they occur is not indicated and the context suggests that they are in the "city ledge" of the Cuyahoga, but they can only be in the Bedford and Berea, since ripples do not occur in the other.

Dr. Edward Orton, Sr., next called attention to the constancy of direction of these ripple-marks in Pike County. In his account of the geology of Pike County he says "the surfaces of successive layers, for many feet in thickness, are often covered with ripple-marks, all of them holding the general direction of north 53° west,

[1] *Geol. Surv. Ohio*, Rept. Progress [in 1869] in Second District, ed. of 1870, p. 68; ed. of 1871, p. 72.

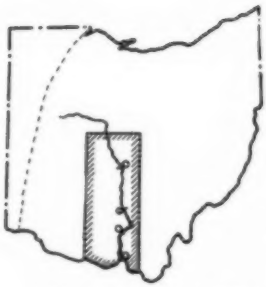

FIG. 2.—Outline map of Ohio showing area represented in large map of ripple directions, and general direction of the Cincinnati axis in Ohio (dotted line across western part).

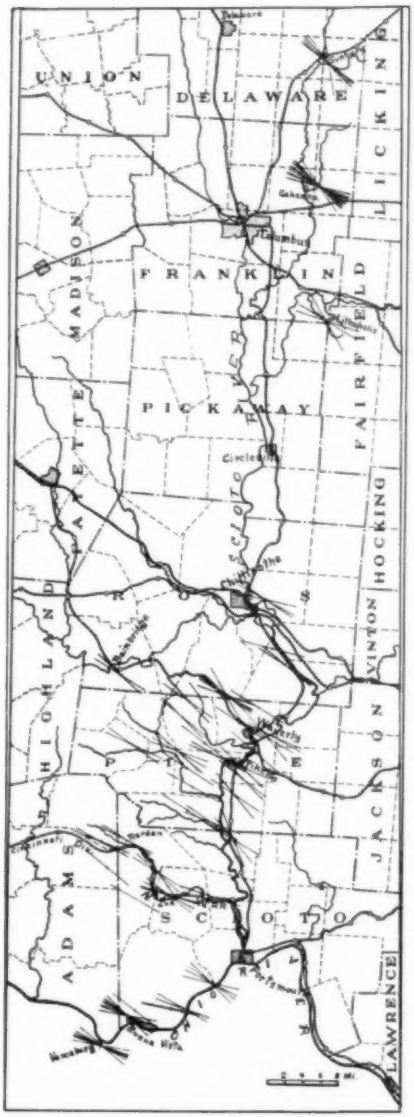

FIG. 3.—Map showing the ripple directions in the Bedford and Berea formations of central and southern Ohio

or south 53° east."[1] In a footnote to the last, he states that Mr. H. W. Overman, the county surveyor, made a careful series of measurements of these directions. "Of twenty-four observations, fourteen were found south 53° east. Four points showed south 65° east; one south 46° east; one south 57° east. The points that showed south 65° east overlie the other exposures, and probably indicate a real change of direction in the wave action."

THE NATURE OF THE RIPPLES AND THE PERSISTENCY OF THE RIPPLE DIRECTION

These observations which are given above in full suggested to the writer that further similar observations over a wider area might prove of value in the interpretation of the geography of the Bedford-Berea sea. Accordingly determinations of the direction of the ripple-marks in both the Bedford and Berea have been made sufficient practically to cover the whole of the outcrop in Scioto and Pike counties and most of Ross County, an area about 50 miles in length (from north to south) by 20 in breadth. Observations at three localities in central Ohio, Lithopolis, Gahanna (Rocky Fork), and Sunbury (Rattlesnake Creek), show that the same persistency continues to the northward, *a total distance from the Ohio River of 115 miles*.

The results of 149 observations have been merely to confirm Orton's observation on the original much smaller area, as to the general direction of the ripples. However, his statements as to the extreme persistency of the 53° angle are not borne out, and, if the area as a whole is considered, no tendency is apparent on the part of the higher surfaces to carry ripples trending more nearly east and west, as he seems to have found them.

At all points where several rippled surfaces are exposed, variation in direction is found, and not infrequently where one surface is exposed continuously for some distance, considerable change may be found in the direction of the ripples which cover it. This, of course, is to be expected. Not infrequently a range of five or ten degrees will be found on an outcrop showing possibly only six or eight surfaces; indeed, as great a range can be found in one ripple

[1] *Geol. Surv. Ohio*, Vol. II, Part 1 (1874), 620.

within a few feet along its length. Just below Denver in Pike County, two widely variant sets of ripples were observed on adjacent planes less than an inch apart, one trending N. 28°[1] W., the other N. 55° W. Such an extreme difference is unusual, but differences of six or eight degrees between adjacent planes can be found without effort. The greatest range noted at any locality is 43°, in the Berea grit below Denver in Pike County. The widest extremes found in the area from Chillicothe southward are N. 22° W., and N. 78° W., a range of 56°. The latter has been recorded several times, especially in the southern part of the area, but the former is an unusual direction. It was found on one plane in the Berea north of Clifford, Scioto County, associated with a number on which N. 60° W. was markedly dominant. In the central Ohio outcrops the extremes are N. 9° W. (on three superimposed planes at Sunbury) and N. 78° W. at Gahanna. This is the absolute range for the whole region, 69°.

Most of the ripple directions noted in the course of the present work have been drawn in on the accompanying map. (Fig. 3.) At some points where a number of directions have been noted, not all are plotted, but in every case where more than one direction has been found, the extremes have been drawn in. On the other hand, at many localities where the ripples persistently trend in one direction, only one observation is plotted, and at almost all points where considerable variation is indicated some one direction lying between the extremes is certain to be dominant, although not so indicated. Thus the map is really a map showing *extremes* of ripple direction, not only areally but vertically. If the directions were drawn in, in the order of their persistency, the amount of variation which exists would largely be obscured, and the unity of the direction would be much more impressively set forth. As it stands, however, it is sufficient to indicate clearly that some factor must have controlled the ripple direction in central and southern Ohio during the time when the upper part of the Bedford and Berea were accumulating.

The ripples are entirely (so far as observed) of the oscillation

[1] Observations are all compass readings. The magnetic declination is one degree or less west of the true north (determined in 1906).

type, that is, formed by the slight forward-and-back motion of the water which is caused by the passage of a wave. Not a single occurrence has been noticed which suggests typical "ripple-drift," the type of ripple which is produced by strong currents of water moving in one direction. The ripple crests are usually from three to five inches apart and rarely reach six inches. This interval varies within a few feet on any surface.

Considerable experimental work has been done on the ripple-marks produced in sand by such waves. Notable is the work by Forel,[1] A. R. Hunt,[2] and G. H. Darwin.[3] The work of these men shows that, when a wave passes over a body of water, the slight oscillation of the water beneath it can be detected to a considerable depth below the surface. To what limit it may extend is unknown. This oscillation sets up small vortices in the water next the bottom, and in the course of time sand ripples are produced by the action of these vortices. These sand ripples are produced at right angles or nearly at right angles to the direction of movement of the wave: that is, they are approximately parallel in direction to the lateral extent of the wave. If the waves on a body of water extend in a northwest-southeast direction (at right angles to the direction of their movement) the ripples generated by them in the sands of the bottom would trend, in general, in the same direction. If we are seeking the factor which controlled the sand ripple directions in the Waverly, we find it directly in the waves which have produced them. It then remains to ask how the direction of water-waves is controlled, and what kept them practically parallel over a wide area throughout a considerable interval of geological time.

Hunt[4] has recorded his observations on ripple direction on the north shore of Torbay which faces the English channel toward the southeast. A portion of the beach examined was so protected

[1] "Les rides de fond," *Archives des Sciences Physiques et Naturelles Genève* (1863). This paper has not been seen by the writer but his results are stated, apparently quite fully, in the paper by Darwin.

[2] "On the Formation of Ripple-Marks," *Proc. Royal Soc. London*, XXXIV (1882), 1–18.

[3] "On the Formation of Ripple-Mark in Sand," *Proc. Royal Soc. London*, XXXVI (1883), 18–43.

[4] *Ibid.*, 6 and 7.

by a breakwater as to receive waves from the southwest only, while farther west along the shore, as the influence of the breakwater became less and less, the waves came from the south and then from the southeast. The beach was examined after a week of calm weather on the day following one on which there had been a slight swell. The sand ripples were found to correspond closely to the direction from which the waves came. Behind the breakwater their trend was northwest-southeast, parallel to the waves coming from the southwest, but as the control of the barrier became less and less to the westward, the ripple directions changed to east and west and then to northeast-southwest, as the waves came from the south, and then from the southeast.

These observations show the independence by wave direction from wind control, the control of wave direction by shore line, and the dependence of ripple direction directly on wave direction.

The parallelism of waves to coasts is generally known, and examples could be multiplied from the beaches of the eastern United States and elsewhere. Since, however, there is no data as to the direction of the ripples induced by these waves, no other need be added here.

In discussing the parallelism of the Bedford-Berea ripples with various persons, it has been suggested that it might indicate the direction of the prevailing wind. In the present geological period the direction of the prevailing winds in Ohio is from the westward. But the actual winds experienced, as a result of the cyclonic control of weather, are so variable that it is impossible to assume that the persistency of the Bedford-Berea ripples could be maintained under similar conditions of cyclonic variation, if those ripples were controlled *directly* by the winds. If they are held to indicate wind direction, we must postulate a series of winds in Bedford-Berea time more uniform in direction, even, than the trade winds, which not infrequently may vary throughout the whole range of the compass in the course of a year, as shown by almost any sailing chart of those regions, and always vary through more than a quadrant of the compass.

On the other hand, granted that the winds initiate the water waves, as soon as they come within the influence of shallow water

they are retarded more in the shallower portions, so that by a process of wave-refraction they are soon brought into a line roughly parallel with the contour lines of the bottom. And the contour lines of the bottom, on all gently sloping coasts, are nearly parallel to the shore line.

The conclusion seems to be warranted that the persistency of direction of the ripples of the Bedford and Berea indicates the prevailing direction of the water waves which formed them, and that this in turn was controlled, either by a shore line or water so shallow as to bring the waves into adjustment parallel to this shore line, or, if it was only shallow water control, to the contours on the sea floor. The shales of the Bedford clearly indicate that there must have been an open sea to the northeastward. Toward the southward the sediments become more sandy and on the whole coarser (the sandstone becomes but slightly coarser but increases very much in relative amount). From this we conclude that either a shore line or shoal water lay toward the southward with decreasing depths of water in that direction sufficient to cause wave refraction. This shore line or the contour of the bottom must have been parallel to the ripple direction, that is, it must have extended in a northwest-southeast direction.

Probably the sea in which these sediments accumulated was of moderate depth, sufficiently so that sedimentation would be continuous. The only evidence of occasional currents which were strong enough to erode locally is found in the middle and upper part of the Berea in central Ohio where the ripples are much less numerous. Quite probably it may have been sufficiently shallow and so well inclosed and protected that currents and waves of oceanic proportions could not develop.

CHANGE IN RIPPLE DIRECTION IN PASSING FROM NORTH TO SOUTH

A brief survey of the map suggests that the directions along the Ohio River tend more nearly east and west than they do farther north. The number of directions occurring within each five degrees has been plotted in four areas. This brings out the fact that there actually is a swing in the direction of the majority of the ripples to more nearly east and west in southern Ohio. In

central Ohio the greatest number trend between N. 50° and 55° W. In Pike and Ross counties by far the greatest number trend from N. 55° to 60° W. In northern Scioto County the maximum is between N. 60° and 65° W., and along the Ohio River it falls between N. 65° and 70° W. The significance of this definite and controlled variation is not apparent at present. The occurrence is merely noted in passing as suggesting one of the methods of attack in such a problem which may yield results.

EVIDENCE FROM THE RIPPLE DIRECTION ON THE ATTITUDE OF THE CINCINNATI AXIS AT THIS TIME

The region of the Cincinnati uplift lies but a few miles to the westward of the area in which the ripples are mapped. This is known to have been a region which from the end of the Ordovician onward tended to maintain a somewhat elevated attitude. According to Schuchert[1] it is one of the positive elements of the continent. That is, it tended to be an island or a region of shallow water while sedimentation was going on in adjacent territories. The axis of the Cincinnati uplift trends nearly north and south, slightly northeast-southwest. With its continuation, the Nashville uplift, the axial trend of the whole is decidedly more northeasterly.

In seeking a coast line which controlled the ripple direction, this positive element suggests itself at once. It has been generally held that there was land in that quarter throughout the Mississippian period and such is indicated on Schuchert's map of this stage.[2] However, by comparing the ripple directions with the present axis of the uplift, as indicated on the outline map of Ohio (Fig. 2), it can readily be observed that the ripples stand almost at a right angle to the axis. If it is supposed that the Cincinnati dome stood high at that time with its axis as at present, it is necessary to assume that within a few miles, certainly not more than 30, to the westward, the ripples were sharply bent into parallelism with this axis. The fact that the ripple direction shows no tendency whatever (the observations are sufficient on this point) to swing into such adjustment to the westward is held to be sufficient

[1] *Bull. Geol. Soc. Am.*, XX (1910), 470.

[2] *Ibid.*, Pls. 78, 79.

evidence that there was no such control in that direction at that time.

Futhermore, the axis which lay to the southward and which did control the ripple directions was directly transverse to the present Cincinnati axis. Whether or not this axis is to be considered as the result of the same forces and conditions which determined the Cincinnati axis, but which were operating in a different manner during Bedford-Berea time, is a question whose answer is, perhaps wholly, a matter of personal opinion. The question is one of some importance in determining the nature of forces and conditions lying back of such a positive element of the continent. The case is of especial interest in view of the fact that, in the Cuyahoga formation which almost directly succeeds the Berea,[1] there is positive evidence of a different nature that the Cincinnati dome had nearly the axial alignment which it holds at present for at least 40 miles north of the Ohio River where the evidence is lost, due to the swinging of the outcrops to the eastward.

In view of the suggestion that the shore line lay to the southward, a word is desirable as to the nature of the Bedford and Berea formations in that direction. W. C. Morse and A. F. Foerste have traced them southwestward into Kentucky for 80 miles and show that the horizon thins rapidly, being reduced at some points to two or three inches.[2] The sandstones and ripple-marks (directions not noted) are still in evidence 18 miles south of the Ohio River where the horizon is only 46 feet thick (as against over 100 in Ohio). Beyond this it is much reduced, and consists almost wholly of argillaceous or calcareous shale, presumably very like the basal Bedford in Ohio.

The authors mention the possibility that only the basal part of the Bedford may be represented in this southern extension, but reject the idea, holding that, even when reduced to two inches, the horizon is "Bedford-Berea." To the writer, who knows the area only from their paper, there seem to be many facts which strongly favor the removal of the Berea and much of the Bedford

[1] The Sunbury black shale, 10 to 20 feet thick, intervenes.

[2] "The Waverly Formations of East Central Kentucky," *Journal of Geology*, XVII, 164–77.

by erosion, prior to the formation of the next succeeding Sunbury shale, and their suggestion cannot lightly be laid aside. These facts are: (1) the presence of a fauna which is found only in the lowermost two or three feet of the Bedford at Gahanna (Franklin County), Bainbridge (Ross County), and Piketon (Pike County), the only localities in central and southern Ohio where the contact has been observed. In Kentucky a portion of the same fauna is found when only a fraction of a foot is present. (2) At one point, Olympian Springs, Bath County, Morse and Foerste note the following variation in thickness of the "Bedford-Berea," within two and one-half miles: 12½ feet, 5¾ feet, 2 inches. This is an extreme case but irregularity in thickness is the rule in the sections they present. (3) The absence of beds corresponding to the Berea as soon as the thickness is reduced to less than 70 feet. (It is not apparent that the 7½-foot bed they refer to the Berea in the Elk Lick section, where the total is reduced to 70 feet, is really Berea and not a horizon in the Bedford. Many such occur in the Bedford to the northward.)

It is thus uncertain, and perhaps unknowable except by inference, what the true conditions in Bedford and Berea time were to the southwestward. If, as seems probable to the writer, only the basal beds are present, they are not indicative, for the basal beds throughout southern Ohio are largely shale.

It seems probable that the northwest-southeast axis in Kentucky, which was prominent enough during late Bedford and Berea time to control the ripple directions, was elevated at the close of that period so far as to permit the removal of almost the whole of these deposits. Possibly this uplift did not succeed the formation of the Berea of southern Ohio, but was contemporaneous with it, and the extension of the Berea (so called) over southern Ohio was due to the northward translation of the shallower water deposits resultant on the uplift. No evidence has been brought forward bearing directly on this point.

SUMMARY

The Berea of central and southern Ohio is largely a phase of the Bedford but is readily distinguished by the much greater amount

of sandstone present. Ripple-marks are abundant in the sandstones of the upper half of the Bedford and most of the Berea. From the Ohio River to the center of the state, a distance of 115 miles and over a width of 20 miles, these ripples are remarkably persistent in direction, trending northwest-southeast. In central Ohio the great majority range between N. 40° and N. 55° W. In passing southward the direction swings gradually to more nearly east and west, the majority on the Ohio River ranging from N. 60° to 70° W. The absolute range of observations for the whole region is only 69°. The cause of the progressive variation from north to south is not apparent.

The general persistency of direction is believed to be due to parallelism to the shore line of that time, which lay to the southward, and the direction of the ripples is believed to indicate the approximate trend of this shore line. If such is the case, it is probable that the Cincinnati axis of that time was not appreciable as an uplift, or, if active, maintained an attitude quite different from that holding at present.

The evidence indicates the presence of shoal water, or possibly a land body, to the south-southwestward the axis of which was almost normal to the present axis of the Cincinnati uplift. From the work of Morse and Foerste it seems probable that this axis became more active later, perhaps closing the Bedford sedimentations with uplift and erosion. The Berea of southern Ohio may be the result of the northward pushing of the strand line by this uplift.

A POSSIBLE LIMITING EFFECT OF GROUND-WATER UPON EOLIAN EROSION

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Mr. C. R. Keyes, in a recent article in the *Journal of Geology*,[1] discusses the well-known fact that in arid regions erosion proceeds independently of sea-level and often is effective even below it. He sets a limit, however, to the depth to which eolian erosion can extend, in these terms: "Where the general ground-water level nearly coincides with that of the plains-surface, deflation can proceed no farther. This level, which is perfectly independent of sea-level, can never be very far below it." In this connection, it may be of interest to call attention to some suggestions regarding the effect which ground-water, existing under a special condition, may have upon erosion.

Mr. H. J. L. Beadnell,[2] in 1909, describes the Kharga Oasis, which is a depression in the Lybian Plateau of Egypt, worn down beneath the general level of the country by the differential effect of subaerial denudation acting on rock masses of varying hardness and composition. He states that the oasis was at one time the bed of an extensive lake, and, from the finding of some fragments of pottery *in situ* in the base of the lacustrine deposits, concludes that the lake was contemporaneous with man. In regard to its origin, he says:

> There is an explanation which it is advisable to keep in mind, though it has never hitherto, as far as I am aware, been advanced as a possible cause of the formation of lakes. . . . . There is little doubt that the beds which we have named the "Surface-Water Sandstone," and which are now exposed in places on the floor of the oasis, were originally entirely covered by impervious clays and contained artesian water under pressure. It is conceivable, therefore, that when

[1] "Base Level of Eolian Erosion," *Jour. Geol.*, XVII (1909), 659–63.

[2] *An Egyptian Oasis: An Account of the Oasis of Kharga.* London, 1909; abstract, *Geol. Mag.*, VI (1909), 476–78.

those beds became exposed at the surface, owing to the removal of the overlying confining strata, their contained water escaped in such quantities as to have given rise to a lake of considerable dimensions.

A lake formed in such a manner would certainly put a sudden stop to the downwearing effects of deflation.

Mr. H. G. Lyons,[1] on the other hand, in an article written many years before, states that during the erosion of the Nile Valley the cutting-back of the escarpment separating the overlying limestones from the underlying Nubian sandstone encroached upon the southern limit of the oases, and let loose springs which greatly increased the rate of erosion. This would appear to be a case where the presence of ground-water facilitated erosion.

Again, Mr. F. J. Bennett,[2] in 1908, seems to have the germ of the same idea, when, discussing the solution-subsidence valleys and swallow holes within the Hythe Beds area of West Malling and Maidstone, England, he suggests that the "upward hydrostatic action of water under pressure . . . . is a new contributing factor in valley formation, and that this in conjunction with subaerial stream erosion" formed the valleys and swallow holes described. This, however, is an application to a region of normal rainfall and is not strictly à propos.

The idea advanced by Mr. Beadnell may be applicable to other desert regions. It is, at any rate, worth considering, in connection with Mr. Keyes's article, as a possible *modus operandi* of one limiting effect of ground-water upon wind erosion.

[1] "On the Stratigraphy and Physiography of the Lybian Desert of Egypt," *Quart. Jour. Geol. Soc.*, L (1894), 531–47.

[2] "Formation of Valleys in Porous Strata," *Geog. Jour.*, XXXII (1908), 277–88.

RECENTLY DISCOVERED HOT SPRINGS IN ARKANSAS

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Though the hot springs at the city of Hot Springs, Garland County, Arkansas, probably have been known since the time of De Soto, the existence of other thermal springs within the state was not even surmised until February, 1908. At that time, a man named J. M. Davis, who was then living in or near the town

FIG. 1.—Caddo Gap, from the south

of Caddo Gap, Montgomery County, discovered other thermal springs issuing from the bed of Caddo Creek in the gap where this stream cuts through Caddo Mountain. This gap is 31 miles west, and 10 miles south of Hot Springs.

As the region about the gap is densely settled, as there has for many years been a small town within a half mile of it, as it is traversed by a wagon road, and as the stream at usual stage is

easily forded where the springs issue, it seems remarkable that they did not attract the attention of someone long ago.

Caddo Mountain is one of the numerous east-west ridges that constitute the Ouachita Mountains of west-central Arkansas. Its height in the vicinity of the gap is 1,250 feet above sea-level, and 600 feet above the stream level. As with all the other ridges of the area, the rocks of this one have been disturbed by folding, and, in addition to the folding, they have been faulted at the gap; and like most of the other ridges, including the one from which the springs of Hot Springs issue, the rocks are of the siliceous type known as novaculite.

At Caddo Gap, the rocks are on edge, and strike north 80 degrees east, across the stream. They are here intersected by a thrust fault, as shown in Fig. 2, with an east-west strike.

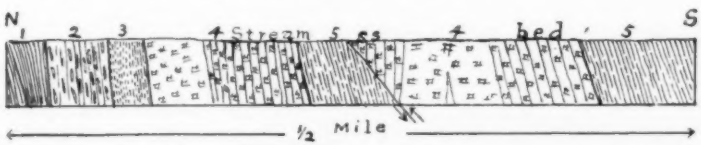

FIG. 2.—Showing the geological section and the rock structure at Caddo Gap. Also, the location of the thermal springs. 5, Stanley shale (Carboniferous); 4, Arkansas novaculite (age undetermined); 3, Missouri Mountain slate (age undetermined); 2, Bigfork chert (Ordovician); 1, Polk Creek shale (Ordovician); *ss*, Thermal springs.

Two springs are known, and their waters rise between the vertical beds of novaculite. Possibly there are others that have not yet been detected. At the time of discovery, all the water of the springs issued below the stream level, but the points of emergence have in part been closed with cement, so that some of the water now issues from the west bank of the creek. For convenience, the springs are here spoken of as the north and the south spring. The surface of the north spring stands about 15 inches and that of the south spring about 10 inches above the surface of the creek at average stage.

The north spring is about 40 feet south of the fault, and the south one 25 feet farther. The temperatures of the two springs, on July 2, 1910, as determined with a physician's thermometer,

were 95 degrees and 96.5 degrees respectively. Doubtless the temperature is much reduced by the water of the creek and if so it varies with the seasons. The rock layers between which the water issues are quite warm to the touch beneath the surface of the stream. From a rough determination, the flow of each spring was calculated as 5 gallons per minute. A small bathhouse has been improvised, into which water from the south spring is pumped by hand.

A sample of the water from each spring was taken by the writer and sent to Dr. W. M. Bruce, chemist of the Arkansas Experiment Station at Fayetteville, for analyses. These analyses and the average analysis of seven of the springs at Hot Springs are recalculated and the results given in the following table:

	Caddo Gap Thermal Springs		Average of Seven Springs at Hot Springs
	South Spring	North Spring	
Constituents	Parts per 100,000*	Parts per 100,000*	Parts per 100,000†
SiO_2	1.5600	1.8700	4.4450
$Fe_2O_3+Al_2O_3$	0.7000	0.7200	.....
K	0.0000	0.0000	0.1934
Na	0.7526	0.3349	0.4421
Ca	3.8876	4.1680	4.9370
Mg	0.2166	0.4235	0.5621
Fe	.....	.....	0.0317
Cl	0.4848	0.7138	0.2819
CO_3	6.8265	6.7085	8.8034
SO_4	0.1419	0.2313	0.7689
Total	14.5700	15.1700	20.4655
Free CO_2	2.0000	1.6000	.....
Grains per U.S. gallon	8.44	8.79	11.88

* Recalculated from analyses by Dr. W. M. Bruce, who gives the constituents as if in (hypothetical) combination; except SiO_2 and $Al_2O_3+Fe_2O_3$. In the recalculation, results were carried out to the fourth place of decimals in order properly to distribute the constituents.

† Recalculated from data given in *Ann. Rep., Geol. Surv. of Ark.* (1891), I, 19, where constituents are hypothetically combined, and are stated in grains per U.S. gallon.

The similarity of the analyses is striking, but this would be expected in water flowing through the same formations, as these do. It will be noticed, however, that the water of the springs at Caddo Gap somewhat excels in purity the springs at Hot Springs, which are themselves very pure.

To the geologist, of course, the interesting thing in connection

with these springs, as with the longer-known ones at Hot Springs, is the possible source of the heat. Is this due to (1) chemical reactions within the rocks through which the water flows, or (2) accumulated heat from friction, or (3) the presence of hot igneous rocks beneath the surface, or (4) the breaking down or other action of radium along the underground course of the water?

The unusual purity of the water seems conclusive evidence against the first hypothesis. Granted that heat from friction can be so accumulated as to bring the rocks to a high temperature, there is no evidence of recent crustal movement within the region where the springs occur. The location of the springs is doubtless due in large measure to the fault, but this probably was formed at the time of the folding, and if there ever was any localized heat accompanying the crustal movements, it would be expected to have been dispersed long ago. Dr. J. C. Branner, many years ago, stated that the temperature of the waters at Hot Springs is probably due to their coming in contact with masses of hot rocks.[1] In support of this, there are outcropping igneous dykes in and near the city of Hot Springs, and igneous areas of some extent only a few miles distant. While there are no known igneous rocks in the immediate vicinity of Caddo Gap, there are small outcrops in the vicinity of Crystal Springs 18 miles to the northeast, and a small igneous area near the town of Murfreesboro, 22 miles to the south. All these igneous outcrops are of Cretaceous or post-Cretaceous age. So it seems not out of the possibilities that the temperature of the water at Caddo Gap is due to its flowing over hot igneous rocks. Whether or not the radium hypothesis has any value probably could be determined by testing the water for unusual radio-activity. This has not been done.

[1] *Ann. Rep., Geol. Surv. of Ark.* (1891), I, 10.

Reviews

The Ore Deposits of New Mexico. By Waldemar Lindgren, Louis C. Graton, and Charles H. Gordon. Professional Paper 68, U.S. Geological Survey, 1910. Pp. 361.

This paper treats a subject about which most geologists have known comparatively little, and of which most of us are eager to learn. Although some of the mining districts were worked by the Spaniards long before the United States became a mining nation, the geology and ore deposits of the state are less well known, perhaps, than those of any other portion of the country. During the past decade several papers treating the deposits of large areas have appeared, and these, the reviewer believes, have contributed fully as much to the science of economic geology as the more intensive studies of small areas. The reconnaissance method of study and treatment gives a perspective which detailed work of small and more or less isolated mining districts could never do. This paper is the most comprehensive and in its scientific aspects should be the most useful of its class. The deposits are so varied and their genesis so clearly discussed that the student of ore deposits will find the paper to possess the essentials of a textbook of mining geology.

Pre-Cambrian rocks do not occupy large areas in New Mexico; the largest masses are found in the north and constitute the southern extension of the Sangre de Cristo Range of Colorado. This belt ends some 20 miles south of Santa Fé. Several other, smaller areas of pre-Cambrian rocks are described. The pre-Cambrian rocks consist of quartzites, mica schists of clastic origin, and some limestones. These are intruded by normal granite, which in turn has been intruded by masses and dikes of dioritic rocks. The latter are at some places cut by pegmatite dikes and by a later granite. Schistosity in varying degrees has been produced in both the sedimentary and the igneous rocks. At some places the granite breaks through or contains remnants of older greenstone tuffs, amphiboles, and rhyolites. The pre-Cambrian sedimentaries probably correspond in age to those imbedded in red granite in various places in Colorado. Perhaps they should be correlated also with the quartzitic Pinal schists of southeastern Arizona.

The pre-Cambrian history, one of sedimentation, mountain building, and igneous intrusion, was followed by long-continued erosion,

which exposed the ancient cores. At the base of the Paleozoic is pronounced unconformity. During Cambrian times a land mass probably occupied the northern portion of the state. South of this, fossiliferous Cambrian beds rest upon the ancient complex. The sea shore moved northward during the Paleozoic, and the Ordovician, Silurian, and Carboniferous beds overlap the Cambrian, and extend farther north. In the northern part of the state the Upper Carboniferous rests directly upon the pre-Cambrian, and these conditions continue as far south as Socorro. The Cambrian consists of quartzite, shales, and limestones; the Ordovician is predominantly of limestone; the Silurian of limestone and quartzite.

The fossiliferous Devonian, represented in the western part of the state, is a thin formation of clay shale, calcareous in the upper portion. At some places it is believed there is an unconformity of erosion between the Ordovician limestone and the Devonian, but at many places they are conformable.

The Mississippian is recognized at several places south of latitude 34°. The Pennsylvanian is deposited with considerable thickness over the whole state, reaching a maximum between Santa Fé and Las Vegas. As far south as Socorro, it consists of sandstone and shales in repeated alternation with limestone beds. Farther south the pure limestone prevails and the total thickness appears to diminish. All indicates near shore conditions in the northern part of the state. The upper Carboniferous is divisible into two groups, the upper one of which is of the Carboniferous "Red Beds." Unconformities of erosion mark both the top and bottom of the group. Triassic "Red Beds" are unknown in the southern part of the state, but have been described in the Sierra Nacimiento.

The Cretaceous rests upon the eroded "Red Beds," the Carboniferous, and the pre-Cambrian. This series consists of pliable shales which once extended over the whole territory with greater continuity than any other formation except perhaps the Early Pennsylvanian.

The Tertiary was marked by igneous activity, mountain making and ore deposition. First, manganitic magmas were thrust out as laccolithic masses beneath the pliable, tough Cretaceous sediments. Marine conditions ceased. Lake basins developed, at least in northern New Mexico. Mountain building accompanied and succeeded intrusion. These forces were active mainly in the belt extending southwestward—the extension of the Rocky Mountain region. The pre-Cambrian core to the north was forced up by faulting or by warping and faulting.

Southward the sediments were broken into faulted monoclines—the typical Great Basin structure. Erosion was active in shaping the mountain ranges, especially in the southwest. A second epoch of igneous activity, distinctly separate from the earlier epochs of intrusion, began, probably in Middle Tertiary, as in Nevada, Colorado, Utah, and in general throughout the central West, and andesites and rhyolites, in places 2,000 feet thick, were extravasated upon beveled sedimentaries. A large Miocene lake covered the upper Rio Grande Valley, in part at least. In this, the Santa Fé marl was deposited. Near the close of the Tertiary, basalts covered this marl, and the eroded older sediments and igneous rocks.

These eruptions continued during Quaternary times. In early Quaternary, land deposits of coarse gravels filled some of the structural troughs to a depth of 1,000 feet. Basalt was poured over these gravels and smaller flows, perhaps only a few hundred years ago, were extravasated at several places.

The highly acidic potash-rich granites, products of the pre-Cambrian igneous period, differ greatly from the Tertiary monzonites, quartz monzonites and their lava equivalents, and it is concluded that these two series could not have been derived from a common magma. It is suggested, however, that the Tertiary rocks were derived from the same source and that toward the last a differentiation took place in a magma basin the products of which were basalts and rhyolites.

The mines of the state, it is estimated, have produced some 35,000,000 ounces silver, and $30,000,000 gold, besides considerable lead, copper, and zinc. Like the area of maximum of orogenic activity, fissuring and igneous intrusion, the deposits extend southwestward, through the state, forming a broad belt about 450 miles long, in which eighty-one mining districts or camps are located. Many types of deposits are represented, among them copper and iron ores in sedimentary beds, fissure veins, mineralized shear zones, lenticular veins in gneiss, replacement veins in limestone, irregular replacement deposits in limestone, contact metamorphic deposits and gold placers. At least three epochs of mineralization are represented: (1) Pre-Cambrian, (2) Early Tertiary, (3) Middle and Late Tertiary. There are also, in the "Red Beds" (Carboniferous and later), deposits which are not related to igneous activities and which were formed presumably by cold solutions, in post-Carboniferous times.

The pre-Cambrian deposits are represented in ten districts. Three types have been recognized, quartz-filled fissures, usually of the lenticu-

lar type; shear zones filled with quartz stringers; disseminations of sulphides in amphibole schists. They are in greenstone, granite, gneiss, or amphibolite. Some of these deposits are accompanied by sericitization and the development of horny silicates in the wall rock. Some have been subjected to the stresses of dynamic metamorphism and show the effect of pressure in lenticular development of quartz and in the development of minerals like biotite. The values are gold, silver, and copper. Minerals represented in these deposits are quartz, calcite, siderite, flourite, tourmaline, biotite, epidote, garnet, chlorite, specularite, pyrite, pyrrhotite, chalcopyrite, galena, zinc blend, molybdenite, tetrahedrite, bornite, and chalcocite. It is suggested that these ores are genetically related to the granite magma. The pre-Cambrian deposits are not extensively developed.

Contact metamorphic deposits are developed where the early Tertiary intrusives, consisting of monzonites, quartz monzonite, granodiorites or their porphyries, cut through limestone or calcareous shale. Metamorphism is not excessive and rarely extends more than a few hundred feet in a horizontal distance. Mineralization usually accompanies metamorphism. Copper, as chalcopyrite, is most common in the contact metamorphic deposits, but is usually accompanied by zinc blend. Magnetite is locally developed. With two exceptions, gold and silver are present as traces only. Galena is generally subordinate; pyrrhotite is not common. Other minerals are quartz, calcite, garnet, epidote, wollastonite, tremolite, specularite, magnetite, pyrite, molybdenite. Some of these deposits are important. Indicating a transition between contact metamorphic deposits and fissure veins formed by magmatic solutions under conditions of less temperature and pressure, there are fissure veins in limestone, the walls of which are in part converted to garnet and other heavy silicates. The magmatic solutions causing contact metamorphism added silica and the metals to the rocks intruded.

Certain veins, not replacements in limestone, are in close genetic relation to the same early Tertiary intermediate porphyries, which locally produced contact metamorphic mineralization. Perhaps $20,000,000 gold has been derived from these veins, which are believed to be of deep-seated origin. In a few of these veins silver is the most important metal. Quartz, pyrite, and gold are almost always present; barite is exceptional. Tourmaline, specularite, pyrrhotite, magnetite, flourite, molybdenite, have been noted. Other minerals are calcite, dolomite, chalcopyrite, galena, zinc blend. Wall-rock alterations are

sericitization, carbonatization, silicification, and pyritization; hydrothermal alterations are less extensive than near the vein deposits of the Middle Tertiary age. At Sylvanite, orthoclase (not adularia) is found in small veins more or less closely related to pegmatites, but which are notwithstanding far from the normal pegmatite.

The Santa Rita (Chino) and Burro Mountain deposits also were probably formed in the first concentration at the time of the intrusion of the early Tertiary porphyries. These disseminated copper ores are greatly concentrated by oxidizing surface waters and resemble in many respects the "copper porphyries" of Arizona, Utah, and Nevada.

Replacement deposits in limestone, not contact metamorphic deposits, form an important group which is likewise in close genetic relation to the early Tertiary intrusions. At Lake Valley the eroded ore deposits are covered by andesite. Strongly indicating deposition by ascending magmatic solutions, these deposits have been found in eight of the districts below beds of shale. In six other districts they are fissure veins. Silver is generally the most important metal; lead is almost always present; gold is absent, barite is rare.

The gangue is siliceous, with one or more carbonates. Other minerals are fluorite, wulfenite, vanadite, zinc blend, pyrite, chalcopyrite, argentite, cerargyrite, silver, limonite, and pyrolusite. No heavy silicates are found in the limestone along these veins, but silica or jasperoid has been developed.

Veins of gold and silver ores connected with volcanic rocks of Middle Tertiary or later age are developed in ten mining districts. They are contained in rhyolites, its tuffs and breccias, or in andesites, which have latitic transitions. Some of these deposits are older than early Quaternary basalts. Base metals and sulphides are not prominent in these veins, lead and zinc are rare, though copper is present in considerable amounts in several districts. The gangue is quartz, which may be accompanied by calcite, fluorite, and barite. Adularia is present in two districts. Pyrite and chalcopyrite are common; bornite is probably primary. Other minerals are zinc blend, galena, chalcocite, telluride, tetrahedrite, cerargyrite, etc. Hydrothermal alteration is widespread. These veins are believed to have been deposited by hot waters very near the present surface at the time of deposition. Possibly the waters, such as those which have been analyzed from hot springs at Ojo Caliente, are solutions of the same genesis and character. The discussion of the relation of the deposits to waters of this character is an exceedingly suggestive and valuable section of the paper.

There are certain lead and copper veins of doubtful affiliation which do not appear to belong to any of the groups described and which seem to have no genetic relation to igneous rocks. They are, so far as developed, of small importance.

The copper deposits in sandstone, which, in part at least, replace carbonaceous material and which appear to have no direct connection with igneous rocks, form a relatively unimportant, but an exceedingly interesting group. These ores are mainly in the "Red Beds." The minerals are chalcocite, bornite, chalcopyrite, pyrite, malachite, azurite, silica, barite, and gypsum. Frequently these deposits replace coal. Some ores carry a few ounces of silver to the ton of chalcocite.

It is believed that the metals known to have been present in pre-Cambrian areas were leached out of these as sulphates, and redeposited in sediments that collected in inland lakes or seas. In part they were deposited as the solid detrital sulphides. When surface waters leached such beds, copper was dissolved. The waters of the Red Beds are known to be rich in chlorides and sulphates. From the organic matter in the beds, hydrogen sulphide would be added, and this would readily precipitate copper sulphide.

Pages 82 to 348 contain detailed descriptions of the many mining districts. W. H. E.

Syllabus of a Course of Lectures on Economic Geology. By JOHN C. BRANNER. Published by Stanford University. 3d ed., 1911. Pp. 503.

This syllabus is intended for the use of students in college and afterward. The method of treatment of the various subjects is mainly by outlines, which are to be expanded by notes from lectures, readings, and observation, and written out on blank pages opposite the outlines. Numerous text-figures and cross-sections of mines add greatly to the value of the book. The references are full, well chosen, and up to date.

W. H. E.

Descriptive Mineralogy, with Especial Reference to the Occurrences and Uses of Minerals. By EDWARD HENRY KRAUS. Ann Arbor, Mich.: George Wahr, 1910.

The book contains 334 pages of text and about the same number of blank pages for students' notes. It is designed primarily for the student of general mineralogy, with little reference to microscopical optics.

The systematic treatment of crystallography which the author published several years ago is not incorporated in the *Mineralogy*. The treatment and the lists of occurrences appear to be comprehensive. As in most textbooks in mineralogy, the references to sources of information relating to occurrences are inadequate. Such references, although adding greatly to its bulk, would vastly increase the usefulness of a textbook on mineralogy. A valuable feature is a group of tables listing separately the minerals containing each element.

W. H. E.

The Pleistocene Deposits in Warren County, Iowa. By JOHN LITTLEFIELD TILTON. Chicago: The University of Chicago Press, 1911. Pp. 42; figs. 7.

As Warren County lies just south of Des Moines beyond the reach of the later ice invasions, the chief Pleistocene features of this region are the sub-Aftonian and Kansan till sheets, the interglacial Aftonian sands and gravels, and the post-Kansan loessial and other deposits. The most serious problem is found in differentiating the sub-Aftonian and Kansan tills, especially since the intervening Aftonian horizon-marker sometimes becomes so scant or obscure as to afford little help in separating the two tills. Though both till sheets were deposited by glaciers from the Keewatin gathering-ground, certain minor differences are cited by the author as distinguishing them. Large pebbles and bowlders are said to be more common in the Kansan than in the sub-Aftonian in the region under study. Among the stony constituents the author notes red quartzite as characteristic of the Kansan but not of the Aftonian and sub-Aftonian, a view supported by a series of pebble classifications made in the typical Aftonian region by the reviewer.

The author assigns much greater thickness to the sub-Aftonian than to the Kansan in the region under study and attributes much of the present topography to drainage lines cut in this older drift during the Aftonian interglacial period, believing that, while the later Kansan invasion has partially masked this Aftonian topography by concealing some of the minor valleys, it has not obliterated the larger ones.

R. T. C.

Petrological Abstracts and Reviews

Edited by ALBERT JOHANNSEN

KOENIGSBERGER, JOH. *Erläuterungen zur geologischen und mineralogischen Karte des östlichen Aaremassivs von Disentis bis zum Spannort.* Freiburg i. B. und Leipzig: Speyer & Kaerner, 1910. Pp. 63; figs. 8; colored geological map in pocket.

This work is a geological description of a small portion of the Alps, $12 \times 26\frac{1}{2}$ km. in extent, between Disentis and Spannort, and just north of St. Gotthard. It is mapped on a scale of 1 cm. to 500 m., on one of the beautiful maps of the Swiss Topographic Bureau in Berne.

The author tentatively submits the following sequence:

1. Deposition of pre-Carboniferous sediments. These were much altered by the later intrusives and are now chiefly sericite gneiss.

2. Intrusions of diorite, diorite porphyrite, diabase, and gabbro-peridotite into Silurian and Devonian rocks. The intrusives are almost entirely altered to amphibolites but the original rocks in most cases can be determined. The diorites are accompanied by differentiation zones of diorite-aplite.

3. Intrusions of gneiss, probably originally granite, into upper-Devonian rocks, and forming a low-arched laccolith. By this intrusion the former eruptives and the sediments were metamorphosed into crystalline schists.

4. Intrusions of syenite, followed by biotite and hornblende granite (Piz Ner), of middle or upper Carboniferous age.

5. Intrusion of the Aar granite at the contact and beneath the previously intruded syenite. In places fragments of the latter are inclosed in the former. Contemporaneously with the intrusion came the Carboniferous folding, seen in the Wendeljoch.

6. The Jura-Trias folding and thrust faulting of the Alps followed next and produced further metamorphism. Nowhere are there exposed in the Aar massif any contemporaneous intrusives.

The rocks are briefly described, numerous analyses are given, and the contact effects are shown. The mineral localities are described, seven excursions are outlined, and complete literature references are given.

ALBERT JOHANNSEN

FARRINGTON, OLIVER CUMMINGS. *Meteorite Studies, III.* Publication No. 145, Geological Series, Vol. III, No. 8. Field Museum of Natural History, Chicago, 1910.

The publication includes: Description of a chondritic meteorite which fell near Leighton, Ala., on January 12, 1907; description of a large iron meteorite found at Quinn Canyon, Nev., in 1908; a collection of analyses of taenite; a tabulation of the well-authenticated times of fall of meteorites since 1800, compared for years, months, days, and hours of the day; and a list of the meteorites of the United States, arranged by states.

E. R. LLOYD

ROSENBUSCH, H. *Elemente der Gesteinslehre.* Third revised edition with 692 pp., 107 figures, and 2 plates. Stuttgart, 1910.

The appearance of a new edition of this standard textbook is a matter of more than ordinary interest since it represents in briefer form the results of the petrographical investigations of the last decade as summarized in the fourth edition of Rosenbusch's *Massige Gesteine.* The fact that the larger and smaller works follow the same general analysis makes the latter especially satisfactory as a textbook for advanced students who can use it.

The new edition has been thoroughly revised and, where necessary, enlarged by the incorporation of new material. The amount of such additional material is much less than might be inferred by an increase of nearly 150 pages which is due in a measure to the resetting of the work. Certain changes in classification, the firmer drawing of the systematic lines, an improvement in proportion (due to the fuller treatment of formerly neglected features), and the introduction of additional chemical data are the chief changes noted. There still remain, however, several changes which might be made to increase the logical coherence of the systematic treatment and the completeness of the chemical discussion.

The book, as in former editions, consists of three parts, dealing respectively with the eruptive (70 per cent), sedimentary (13 per cent), and metamorphic (17 per cent) rocks, preceded by an introduction.

The "introduction" remains practically unchanged except for the substitution of the new average for the composition of rocks obtained by Clarke and a brief discussion of the cone-in-cone structure.

Part I, "The Eruptive Rocks," following the earlier analysis, considers them from the viewpoint of their substance, geological occurrence,

texture, age, metamorphism, and classification. Three additions of moment are noted. These are discussions of (1) gases, based principally on the work of Gautier without reference to that of R. T. Chamberlin; (2) the relation of size of grain to the temperature in a cooling intrusive mass, based on Professor Lane's paper; (3) applicability of the phase rule to the complex hydrous and gaseous solutions of more or less dissociated material of the magma which is not an arbitrary mixture but such that when computed water free contains 184 molecules.

The systematic description of the igneous rocks divides them into three major groups—deep-seated, dike, and effusive—as formerly. The groups, in turn, are divided into 10 families, three subgroups, and 14 families respectively. Each family is described with respect to its mineral and chemical composition, texture, subdivision, geological occurrence, and distribution.

The discussion of *deep-seated rocks* shows careful revision and the incorporation of many of the results of the recent investigations. The systematic treatment is conspicuously modified by placing the discussion of the Peridotites last and by the expansion of the chapter on Ijolite and Missourite into two chapters entitled "Missourite and Fergusite" and "Ijolite and Bekinkinite." Less conspicuously there is introduced the far more fundamental conception of the division of the deep-seated rocks into three great series by the elevation of the Charnockite-Maugerite-Anorthosite series to equal rank with the better known alkali and alkali-lime series. The new series is characterized as follows:

Charnockite-Anorthosite Series.—The rock series based upon gradations in composition and association in the field passing from Granite through Syenite and Diorite to Gabbro—the lime-alkali series—and that from alkali granite through alkali syenites to Essexites, the alkali analogue of the gabbro—the alkali series—have been well recognized. There have, however, in these series been certain members lacking, e.g., the alkali analogue of the Diorite and the lime-alkali analogue of the Nephelite syenite.

Each of the series has its own areas of occurrence and the different members of a series are usually intimately related in occurrence while members of the alkali series never occur in regions of lime-alkali rocks.

We find now among the Plutonic rocks, a type whose mineral composition is of the same sort as the gabbro—the anorthorite and labrador fels—which, notwithstanding its chemical character and association, varies throughout from the gabbro. This anorthorite type we find in association with the hypersthene granite or charnockite, and here, moreover, the silica-rich charnockite is connected by a number of intermediates with the silica-poor anorthosites, so that we may speak of a charnockite-anorthosite series which even has peridotite or pyroxenic end members. . . . .

The number of occurrences of rocks of the charnockite series is, on the

whole, not as great as those of the other two series and especially the intermediate members between the charnockite and the anorthosite are as yet but little studied.

The series includes charnockite, maugerite, anorthosite, and kyschtymite, and is represented in Canada, Norway, Russia, Saxony, and the type locality of Madras described by Holland.

The analyses show with a rise in silica a decrease in anorthite and, when this is over 56 per cent, the content of the alkalies, producing microperthites, rises rapidly at the cost of the lime-soda feldspars until the granitic type of the series is reached.

The uncertain touch in handling this new series is striking evidence of the evils of combining the elements of genesis and composition in a systematic presentation of rocks. Either the integrity of the series rests upon the chemical similitude of its members or in their genetic association. It cannot rest on both as of equal supporting value. From the treatment of this new series by Rosenbusch it is impossible to credit him with a clear concept without charging him with serious defects in revision. The series is introduced incidentally (p. 182) without any forecasting of its existence in the general discussion or in that of the granites where a typical member of the new series (Hypersthene granite from Birkem) is cited as a member of the alkali-lime granites, at least by implication. Moreover, charnockite itself is described briefly (p. 94) without reference to the new series, while the index to the volume itself shows no reference to its discussion on p. 182. That it is possible to erect a new series may be seen from a study of Osann's analysis, since rhyolite, micatrachyte, dacite, amphibole-andesite, aplite, granite, and alaskite show the chemical characteristics assigned to the series, viz., relatively high alumina, lime, and the alkalis, low iron, magnesia, and varying silica.

The discussion of the Essexites, the Shonkinites, and other "basic alkali" deep-seated rocks has been entirely rewritten and expanded by embodying the results of the studies of Hibsch in Bohemia, Lacroix in Madagascar, and others in different areas.

The chemical discussion at the end of the chapter on the deep-seated rocks is enriched by the graphic representation of the analyses according to the scheme proposed by Osann and by a short tentative discussion of the molecular character of the magmas.

The discussion of the *dike rocks* is little changed from that of earlier editions. A slight modification in terminology from granite porphyry to *granito-porphyritic* is noted at the beginning but not consistently followed, and the introduction of granito-porphyritic rocks equal to the alkaline and basic alkaline rocks has been made to improve the symmetry

of the discussion. The treatment of the eleolite-porphyries has been rewritten and a section describing the monzonite and shonkinite-porphyries has been added. The fine-grained rocks are divided as formerly into aplitic and lamprophyric series, the former subdivided on the basis of habit, the latter on the geological association and ferromagnesian constituents. Much of this description has been rewritten. The additional section on the camptonitic, monchiquitic, and alnoitic rocks emphasizes their genetic and geological association with the deep-seated rocks of the alkali series and this relationship is accentuated by the introduction of a number of analyses and an Osann diagram.

The discussion of the *effusive rocks* has largely been rewritten with a marked increase in the chemical descriptions which are supplemented by the introduction of many new analyses. The chief changes of viewpoint occur in the expansion and elaborated classification of the alkali rocks and in the addition of a lamprophyric group of effusive rocks analogous to those distinguished among the dike rocks. The keratophyres are now classed with the porphyries of the lime-alkali series because of their geological association, although it is recognized that by mineralogical and chemical composition they are often practically identical with rocks of the alkali series.

The section on the *trachyandesites* is entirely rewritten and the line of separation between them and the normal dacites and andesites is emphasized by the introduction of numerous analyses and an Osann diagram. The treatment of the *basalts* and *melaphyres* remains with little modification, the author still holding to the distinction of the 3 types on the basis of age, although the citation of examples, e.g., the Mesozoic diabases of the United States, is manifestly contrary to the basis of classification adopted. The correlation of the trachydolerites as the effusive form of the essexite-magma is no longer maintained, the view being expressed that their systematic position must be postponed pending the accumulation of additional information.

The lamprophyric effusive rocks are characterized by their low content of alumina and the almost constant predominance of magnesia over lime. The erection of this new division is based upon the conception that the surface equivalents of the more acid rocks are really more aplitic in their composition and that one would naturally expect to find analogous lamprophyric equivalents as well. To this division are assigned the verite, fortunite, and jumillites of Osann, the orendite-madupite group (and Prowersite) of Cross, the euktolite, coppaelite, absarokite, selagite, and sanukite.

Part II, devoted to the "Sedimentary Rocks," remains practically

unchanged beyond minor additions to bring the work up to date. The treatment of the carbonate rocks is somewhat expanded by a discussion of the *marls*, and the origin of *oölites*, and the origin of *dolomites*. The origin of the oölitic iron ores is also discussed in an additional section. The changes in organic matter by which coal and oil are formed are classified in accordance with Potonié's recent paper.

Part III. The third part, dealing with the "Crystalline Schists," has been thoroughly revised and brought down to date without any serious modification. Greater emphasis is laid on the chemical composition as an indication of the character of the original rock and here and there the discussion is an application of physical-chemical conclusions to the interpretation of the phenomena. Reference is made to the schistosity developed by crystallization under pressure as described by Riecke and the terminology is modified by the introduction of the terms proposed by Becke. In the descriptive portion no change is made in the systematic treatment, beyond the introduction of a few new names, such as the *myrmekite* of Sederholm, the *astochite-gneiss* of Belowsky, and the *sagvaudite* of Pettersen.

While the book as a whole is probably the best elementary textbook in descriptive petrography because of the clear style and comprehensive treatment of the subjects, it must be regarded as falling short of the ideal in the minds of all who find occasion to criticize the continental viewpoint, which has in large measure been developed through the writings and teachings of Rosenbusch. The criticisms against the validity of the dike rocks and the Kern theory are too well known to need restatement. There are, however, numerous inconsistencies in the systematic carrying-out of the underlying views which should be eliminated. For example, the element of age is discarded in the general discussion but frequently appears in the definitions or descriptions of the various rocks. There is likewise ground for criticism in the combined use of geological and petrographical criteria in classification which leads to the separating of rock like the keratophyres from the alkali rocks from which they are admittedly indistinguishable in chemical and mineralogical composition and in texture. A third criticism in systematic treatment is that already referred to in the handling of the charnockite and anorthosite series and the relative disregard of the silica content in the chemical discussion by the use of the Osann diagrams. It is a subject for regret that this excellent textbook cannot be translated and still more that there is no equally satisfactory work by an American author.

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